RELATIVE IMPORTANCE OF CLIMATE CHANGE AND WATER DEMAND FOR RESERVOIR FEASIBILITY

by

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ABSTRACT

Climate change is projected to modify the hydrologic cycle across scales, but the relative impact climate change will have on water resources systems compared to other influencing factors remains uncertain. The performance of water storage reservoirs, for example, will not only be altered by climate-change-modified precipitation, runoff, evaporation, and transpiration, but also by additional factors such as water demand. Using a case study set in the western United States, this thesis presents an investigation of the relative importance of climate change modified hydrologic processes and water demand on reservoir feasibility. A modeling framework comprised of a river system model (MODSIM-DSS) and a precipitation (rainfall and snowfall) driven runoff model (Snowmelt Runoff Model) was created, calibrated and validated for the White River watershed and river system in northwest Colorado and northeast Utah. After validation, a proposed reservoir in the Utah segment of the White River was inserted into the modeling system. Based on climate change projections of impacts to hydrologic processes, scenarios reflecting climate change modified precipitation, temperature, and evaporation were defined and combined with a future water demand scenario including energy development and urban growth requirements. The scenarios were analyzed with the modeling system to quantify the relative impact of the altered hydrologic processes and increased water demand on reservoir feasibility. The results showed a reduction in precipitation has a greater effect than the projected increase in temperature and

evaporation on the inflows to the proposed reservoir and performance of the reservoir. For a 7 percent decrease of precipitation there was an 8 percent reduction in runoff volume over a simulated ten-year period. This decrease was shown to have the greatest impact on the amount of water stored in the reservoir and the amount readily available for downstream use. In a simulation of the combined effects of precipitation, temperature and evaporation modification the reservoir was found to be impacted significantly with insufficient storage to meet downstream demands. Although significant, the impacts of the climate change modified hydrologic processes on reservoir feasibility were found to be insignificant compared to the impacts of future water demands.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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CHAPTER 1

INTRODUCTION

As humankind continues to grow and expand across the Earth, the amount of greenhouse gases that are being released into the atmosphere is also growing. Over the last 50 years, an increase in the Earth's surface temperatures has been measured. There is a growing body of evidence to support the notion that greenhouse gases released into the atmosphere are a major contributor to Earth's rising temperature (Mitchell et al., 2002). Representing an overwhelming majority of the scientific community, the Intergovernmental Panel on Climate Change (IPCC) reports that the climate is changing and that anthropogenic release of greenhouse gases is playing a role. Studies have predicted that by 2050 the global mean temperature could increase as little as 1.5°C (2.7°F) or as much as 4.5°C (8.1°F) (Stainforth et al., 2005; Kerr, 2004). These changes to the Earth's climate are expected to have significant impacts on the water cycle and water resources systems.

The Earth's atmosphere is a giant machine that receives 175 petawatts (PW) or 175 quadrillion watts of energy from the sun. The majority of this energy makes it way to the Earth's surface and is ultimately emitted back to space as infrared radiation (Kiehl et al., 1997). However, it has been noticed that atmospheric concentrations of many gases have increased over the past several decades. These gases are trapping thermal energy within the atmosphere not allowing the infrared radiation to return to space, leading to global warming (Collins et al., 2007). This process, more commonly known as the greenhouse effect, involves the emission of gases including carbon dioxide, methane, nitrous oxide and halocarbons; all of which are generally associated with energy use (Karl et al., 2003). While these gases are a major contributor, it should be noted that they are not the only contributor; on a local, regional, and global scale, urbanization and land use changes will also have an impact.

As indicated by the IPCC, there are several factors that are being affected by climate change. Temperature is the first parameter that has been recorded as increasing over the past several decades. Climate change is affecting nature on a global scale as noted by the reduction in glaciers and sea ice around the world. The Arctic has warmed faster than the rest of the Northern Hemisphere by 50 percent (McBean, 2005). On a more local scale, the Arapahoe Glacier in Colorado decreased in volume during the twentieth century, however since 1960 the reduction has been very little (Barrett et al., 2003). The amount of green house gases in the atmosphere will most likely cause more warming, some studies indicate there could be a rise in temperatures of 0.6°C (1.0°F) per year (Hansen et al., 2005; Wigley, 2005). Climate models attempting to predict what future temperatures will be indicate that higher elevations will experience a larger increase in temperature (Bradley et al., 2004). However, others have predicted that altitudes higher than 10,000 feet above sea level will experience a cooling (Diaz, 2004).

Any change in climate, whether it is an increase or a decrease, will undoubtedly affect the hydrologic cycle. The hydrologic cycle is a network of variables linked together in such a way that as one parameter changes the effects may cascade to other linked hydrologic processes. There are many theories that hypothesize how precipitation is going to change with higher temperatures. One mode of thinking is that the annual average precipitation will increase (Smith et al., 2006). However, this does not imply that every part of the world will experience an increase in precipitation, rather the theory indicates that some parts will receive more and other parts will receive much less. Also with changing temperatures, precipitation temporal pattern and frequency, duration, and intensity of rainfall may also change (Trenberth et al., 2003). Studies have been conducted on a more regional scale for the Rocky Mountain region. According to these studies, it has been estimated that with a 1.6°C (2.9°F) temperature increase the precipitation will decrease by 2 percent to 7 percent (Smith et al., 2006). Increased temperatures leading to decreased precipitation for the Rocky Mountain region may have a great effect on the hydrologic cycle that maintains the water resources for the region.

With a changing climate and an altered hydrologic cycle, other components besides temperature and precipitation will be altered. Higher temperatures are expected to increase evaporation and transpiration (Pappas et al., 2007). Since evaporation is a major component in the hydrologic cycle it is important to understand how much evaporation will be affected by climate change. A study was performed in Texas about how evaporation and transpiration will be affected by climate change. It was concluded evaporation may increase or decrease given climate change conditions, depending on the season (Marshall et al., 2008). This is because the warmer climates will alter the length of the growing season; therefore, the amount of evaporation and transpiration that could occur in a given year will be changed (Neitsch et al., 2001). Other studies have looked at large water bodies to determine how the net evaporation is being affected by climate change. In Wisconsin a study was performed that determined evaporation rates are more affected by the net radiation than temperature and humidity (Lenters et al., 2005). With the accumulation of green house gases, less radiation will be returning to space therefore altering the net radiation (IPCC, 2001). The altered radiation will alter evaporation values ultimately having an effect on water resources for a given region.

With a modified hydrologic cycle, reduced precipitation, increased evaporation, and transpiration, both current and future reservoirs will be affected. Society relies on reservoirs to provide the storage of water to equalize the inflows to provide a controlled outflow to meet year-round water demands. However, if a reservoir receives less spring runoff, then the reservoir will not fill completely. If there is increased evaporation, then the reservoir will lose more water than what it once did. Also, plants could potentially consume more water depending on the region and crop type the irrigation water demands could increase or decrease (Tung et al., 1998). However, all research on this topic agrees that with increased temperatures the growing season will be longer (Brumbelow et al., 2001). As water resource planners analyze existing reservoirs and assess feasibility of future reservoirs the relative impact of climate change on the reservoir performance remains an uncertainty.

The goal of this thesis is to determine the relative importance of selected important climate change modified hydrological processes and future increased water demands on reservoir feasibility. The guiding hypothesis is increasing water demands from population growth, energy development, and more has a greater influence on reservoir feasibility than the climate change modified hydrologic processes. The modified hydrological processes changes to evaporation are expected to be of greater concern for reservoirs in semiarid climates. The investigation focuses on the White River in Colorado and Utah because the system is driven by snowmelt runoff, is relatively compact and feasible to analyze, and is currently projected to have significant water demand increases in the time period corresponding to climate change projections. A modeling framework comprised of a precipitation runoff model and a river/reservoir management model is applied to the White River system to simulate the impacts on the performance of a proposed reservoir from projected climate change modifications to precipitation, temperature, and evaporation and the projected increased water demands. The modifications to precipitation, temperature, and evaporation are based on published projections for the region and to account for uncertainty of the projections a range of scenarios reflecting incremental increases in magnitude of the projected impact is used. The increased water demand is based on a quantification of existing approved water rights and a detailed analysis of the amount of future water needed for potential energy development and urban growth in the region over the next 50 years. The modeling framework is calibrated and validated with recorded precipitation, streamflow, and meteorological observations and available water rights information. The reservoir performance is assessed by simulation results showing the functionality of the reservoir in terms of its ability to meet downstream water demands as it would be designed to do.

CHAPTER 2

METHODS

The relative importance of hydrologic process modifications from climate change and water demand increases is investigated with computer models of runoff, stream flow, and reservoir routing. Runoff from the watersheds is simulated with the Snowmelt Runoff Model (SRM) and the water budget in the White River is simulated with MODSIM-DSS. Through calibration of the models a water balance through the White River system will be computed incorporating reservoirs, inflows, extractions due to water demands associated with existing water rights and projected future demands. The models are parameterized using available data and calibrated and validated with precipitation and stream flow observations. The following subsections describe the White River system, the data used to develop the models and the study methods.

2.1 White River System

In the State of Utah there are several reservoirs that supply necessary water to downstream users. However, with a growing demand, it is may be necessary to find new sources and develop these sources. One of the projected future significant demands is for energy developments, such as oil, oil shale and natural gas. The Uintah Basin, in Eastern Utah, has the potential of large amounts of energy developments. Potentially, several million barrels of oil and natural gas resources may be extracted from this basin. Oil shale resources, for example, in the Uintah Basin and nearby Piceance Basin in Colorado have been projected to have sufficient reserves to eventually produce one quarter of the U.S. oil demand (Bartis et al., 2005). However, the production of the energy resources would require massive amounts of water although the exact amount remains uncertain (Burian et al., 2009). One of the possible options to develop more water to meet current and projected needs in the basin is to construct a reservoir. The White River, in the South-Eastern region of the Uintah Basin, has been proposed as a potential location for a reservoir.

The White River Watershed consists of two major watersheds, the upstream watershed in Colorado and the downstream watershed in Utah (Figure 1). The upstream watershed in Colorado is the source of the significant majority of the flow in the river. In Colorado, the upper watershed has a flow through reservoir (Taylor Draw Dam) that currently provides water for residents and agricultural uses. The reservoir regulates the flows on the White River by releasing either 200 cfs or natural stream flow, whichever is less. In order to evaluate the effect climate change will have on the White River flows, it is necessary to generate a runoff model for the upstream watershed since the majority of the flows are generated from mountain runoff.

The downstream watershed is in Utah and consists of the White River and Evacuation Creek. Both watersheds are rich in many natural resources including oil shale, oil sands, gilsonite and natural gas. The White River is one of the main tributaries to the Green River flowing at a daily average of just over 600 cfs. The city of Vernal is approximately 40 miles north of the river’s confluence with the Green River. There are not many developments that currently have valid water rights in the downstream

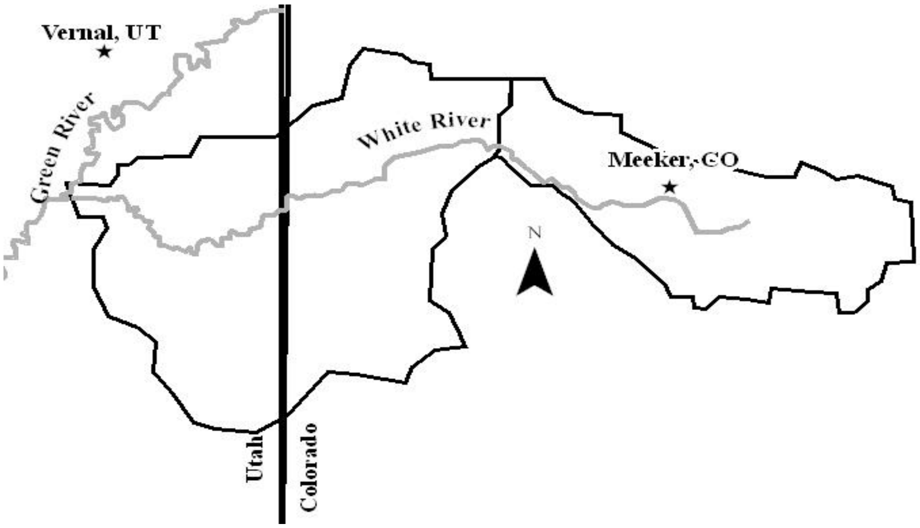

Figure 1 Location of White River watersheds on the Utah Colorado border

watershed. However, at the termination of the White River, prior to entering the Green River, there is a Native American reservation that holds water rights with early priority dates and the Federal Government holds historic rights for wildlife.

As stated previously, the White River originates in Colorado and terminates when it flows into the Green River near Ouray, Utah. Prior to entering Utah, Colorado water users divert water along and near the river in order to irrigate land and raise cattle (Figure 2). Several USGS stream gauges are located on the river providing streamflow observations dating to 1923. In Colorado there has been more development near the river because the land is more readily accessed, however in Utah the development is minimal. The reasons for this are many; the two main reasons are that the majority of the land is owned by the federal government and the area is very inaccessible (Uinta Basin State Water Plan, 2002). Therefore, with a higher cost to develop the land, many people have decided to homestead where the land is easier to make profitable.

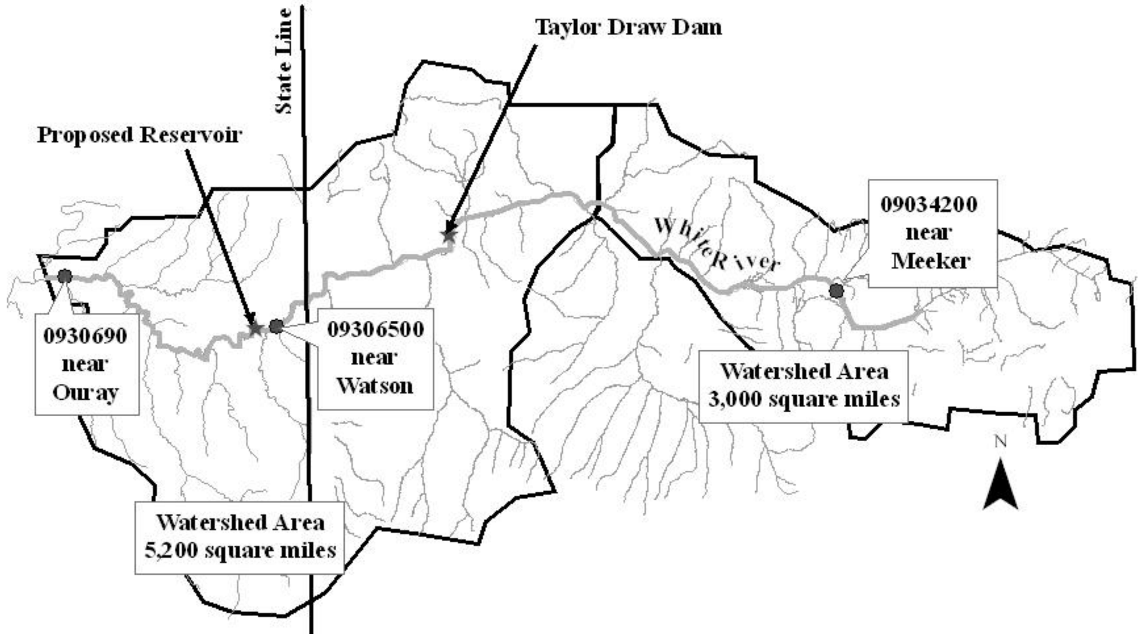

Figure 2. View of the White River system with the existing reservoir and the proposed reservoir

The White River system provides a suitable case to investigate the effects of climate change impacts on hydrologic processes and increasing water demands on the feasibility of a reservoir. The proposed reservoir might provide the ability to meet future water demands and the flows into the reservoir are driven predominantly by snowmelt runoff. When planning for the future, there are several issues that need to be accounted for in determining if the river and reservoir will be able to provide water for current water users and future water users. This can be accomplished by knowing how many water rights are currently diverting water from the river and how much water will be required for development (energy, urban, etc.) in the basin.

Since energy development requires significant amounts of water a reservoir on the White River might be a necessary element to encourage energy development in the Uintah Basin. The need for and possible locations for the dam site and reservoir have been investigated by Bingham Engineering Firm in conjunction with the Utah Division of

Water Resources (Utah Division of Water Resources, 1979); yet its location, form, and need remain uncertain and in need of further study, especially given the lack of consideration for potential implications of climate change. Although the location of the proposed reservoir remains undecided, there has been a suggested location (39^{o}57’48.64” N 109^{o}12’39.37” W) that will serve as the basis for this case study. This location is directly downstream from the U.S. Geological Survey (USGS) stream gauge 9306500 (Figure 2). The estimated size of the reservoir is shown in Table 1 (Utah Division of Water Resources, 1979). These estimates were obtained from a historic report written in the 1970s. The reservoir capacity was tested and proved to be a viable option for energy development based on past projections of energy development water requirements. New projections of water requirements for energy development and new estimates for climate change implications on streamflow need to be factored into the analysis.

The developable oil in the Uintah Basin is not the same oil as they develop in the Middle East. Utah’s oil supply is in the form of oil shale. Oil shale is comprised of fine-grained sedimentary rock bound with kerogen (Utah Heavy Oil Program, 2007). When the bitumen is heated, a petroleum-like liquid is released (Bartis et al., 2005). There are

Table 1. Reservoir parameters for proposed White River reservoir in Utah

Outlet capacity	1,300	cfs
Reservoir capacity	105,000	ac-ft
Minimum capacity (inactive storage)	38,000	ac-ft
Active storage capacity	67,000	ac-ft
Reservoir Length	11	miles
Reservoir Width (maximum)	0.7	miles
Dam Height above streambed	129	Feet

two methods to extract oil shale – (1) mining and surface retorting and (2) in situ retorting. Both require water to execute the process, regardless of the mining technique.

In order for oil to be produced from shale the bitumen is heated at 900~1000 ºF in a surface retorting plant or in-situ. Once this process is complete the oil from shale becomes a liquid and needs to be refined. These are potentially water intensive processes (Burian et al., 2009) and they need a reliable water source in order to economically be developed (OTA, 1980). Moreover, the water requirements for energy generation to support the energy intensive mining and refining operations and the water requirements to support the urban growth necessary to sustain the oil shale industry must also be factored into the estimate for future water demands (Burian et al. 2009).

2.2 Model Development and Validation

2.2.1 Model Overview

Two computer programs are used to model the White River watershed. The model simulating the precipitation runoff including snowmelt runoff and rainfall runoff is the Windows version of Snowmelt Runoff Model (SRM) (Martinec et al., 2007). This model takes into account meteorological parameters such as temperature and precipitation to calculate the amount and timing of the runoff. The MODSIM-DSS water management model (http://modsim.engr.colostate.edu/index.html) is used to accept runoff from SRM and simulate the flows through the system.

2.2.2 Snowmelt Runoff Model (SRM)

The flows in the White River are almost entirely generated by the snowmelt runoff in the upstream watershed. Using Watershed Modeling System (WMS) (Aquaveo,

2008) and SRM (Martinec et al., 2007) a watershed model for the upper watershed was created (Figure 3). First, digital elevation model (DEM) of the watershed was acquired and processed to delineate the watershed boundary and identify terrain zones in SRM. The SRM terrain zones represent specified elevation ranges based on the location of the Snow Telemetry (SNOTEL) sites within the watershed. For the upper White River watershed in this case study, four zones were defined by elevation, but one zone is small and does not contain a SNOTEL site and was thus merged with an adjacent zone producing three terrain zones in the SRM model (Figure 4).

The information from the DEM needed for SRM is shown in Table 2. Meteorological data (temperature, precipitation) and the snowmelt rate needed by SRM were acquired from the SNOTEL data. Temperature data can be entered in SRM as the

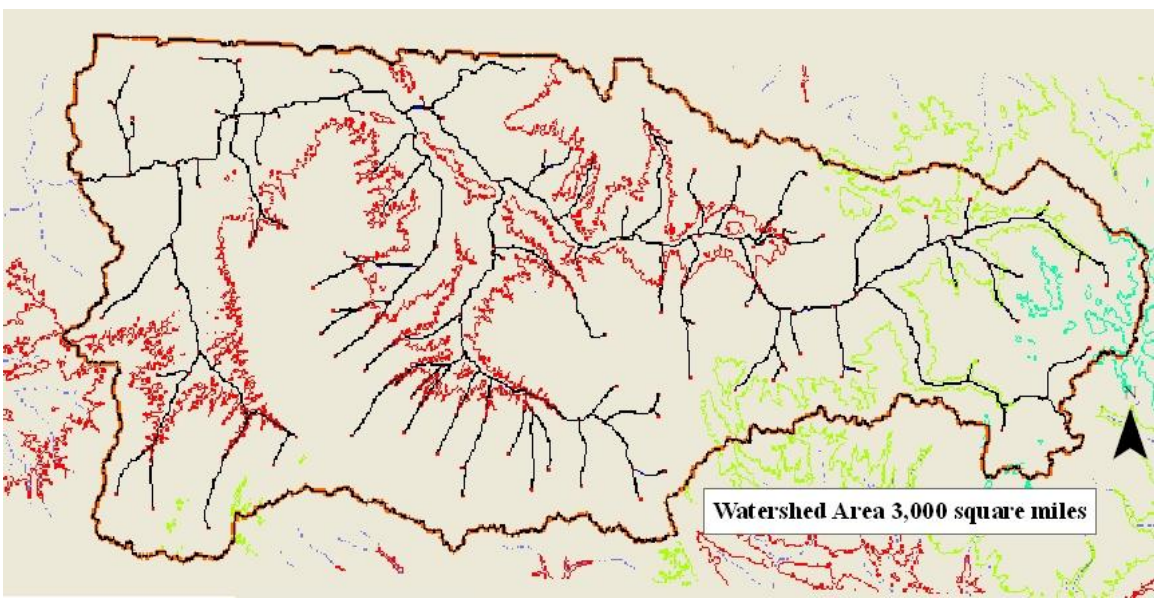

Figure 3. DEM in WMS used to calculate the area of the watershed and zone areas

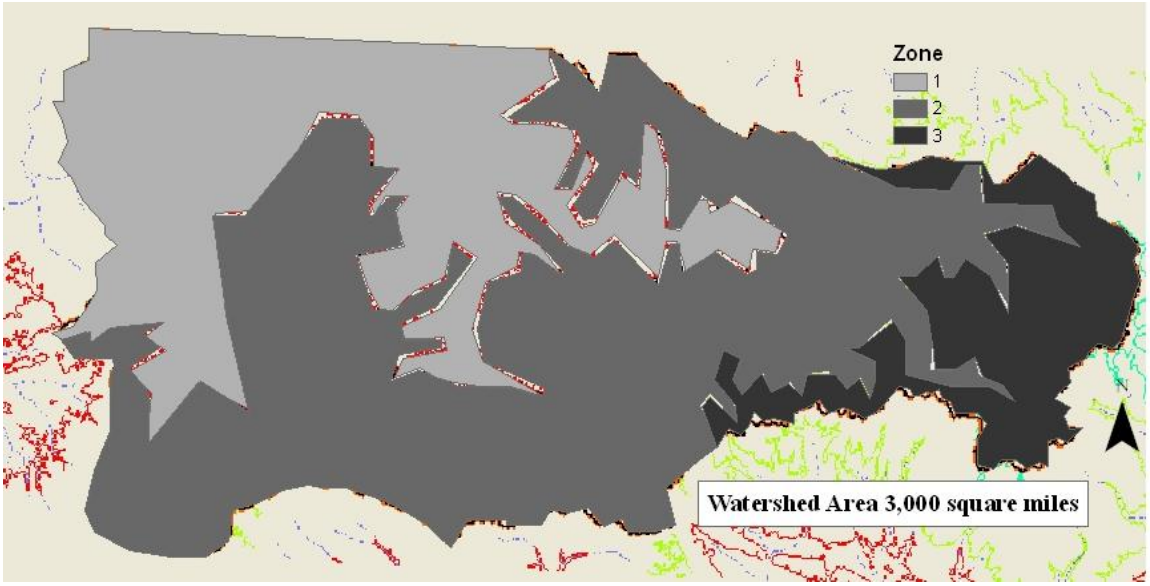

Figure 4. Delineated zones used for the SRM

Table 2. Data used to generate a snowmelt runoff model for the White River watershed

Zone	Area (mi^2)	Area (km^2)	Elevation (ft)	Elevation (m)
1	1,804	4,671	6,560	2,000
2	902	2,336	8,856	2,700
3	301	779	11,152	3,400
Total	3,012	7,786		

average or as a maximum and minimum data pair. For the White River watershed, the majority of a given day will have temperatures nearer to the minimum than the maximum and there are wide temperature swings. Therefore, the minimum and maximum temperatures were used in the upper White River watershed SRM model. Precipitation is entered as incremental values representing rain or snow storms. A critical temperature parameter (usually one or two degrees above the freezing temperature) is provided to direct SRM to simulate the precipitation as rain or snow. The critical temperature is usually adjusted during model calibration.

The snow melt rate used by SRM defines when snowmelt initiates for a specified terrain zone. This is another parameter typically tuned during calibration. For this case study the snowmelt rate is defined from the depletion curves calculated using recorded snow pillow data and snow water equivalency (SWE) data from the SNOTEL sites. Because lower elevations begin melting before higher elevations, a depletion curve needs to be generated for each elevation zone. Figure 5 shows the depletion curves. The decline in the curve indicates snowmelt initiation and the rate of decrease in the curve represents the melt rate. The curves are then numerically represented in the model based on the day melt begins and how much melt occurred. In the calibration process the melt-rate curves are crucial for the modeled runoff to mimic the observed runoff. Shifting these curves ahead by a week or delaying them by a week will alter when the snowmelt begins, ends and peaks.

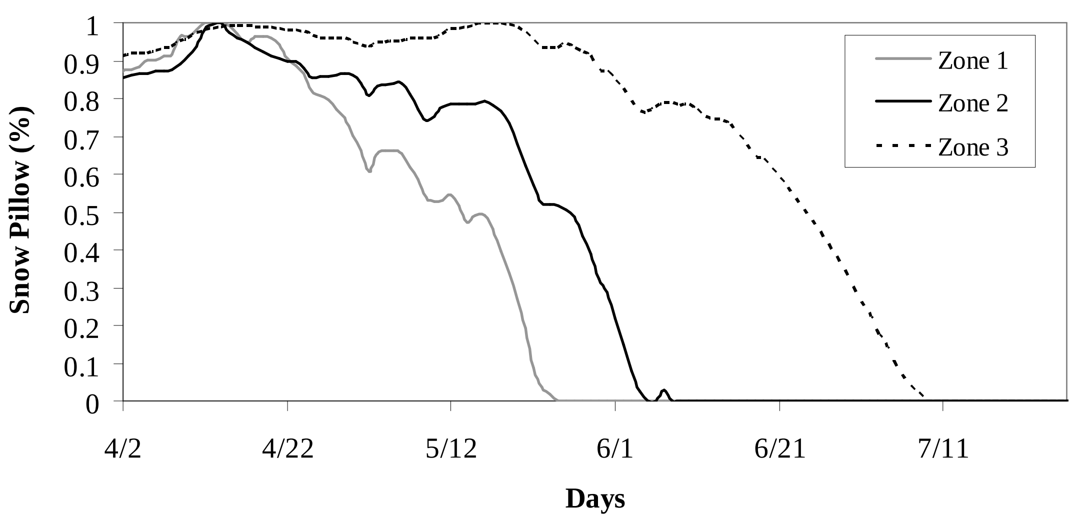

Figure 5. Depletions curves for the three SRM terrain zones in the upper White River watershed

The heart of SRM is a single equation that generates the discharge for each day in each zone. The discharges from the three zones are summed to produce the total discharge for the day. The runoff coefficients define how much water infiltrates prior to runoff generation. Adjusting the runoff coefficients alters the total volume that occurs during the simulation period, but does not affect the timing of runoff. The main SRM equation and the parameters are described in more detail in Appendix A.

To calibrate SRM, water year 2007 was selected because it represents an average precipitation year and reliable precipitation, SNOTEL, and streamflow datasets were available. The initial SRM simulation produced discharges well below observations and the timing of the simulated runoff was much later than observed. Therefore, the snow runoff coefficient was changed from the default value 0.7 used in the initial simulation to 0.02. The rain runoff coefficient was similarly reduced from 0.6 to 0.1. This change effectively reduces the amount of snowmelt or rainfall that infiltrates into the subsurface, effectively increasing the discharge magnitude. These adjustments are consistent with adjustments routinely made by Natural Resources Conservation Service (NRCS) for similar basins (Julander, personal communication, February 2010). The depletion curves were also adjusted and additional fine tuning of the runoff coefficients was performed until a satisfactory match with observations could be obtained as shown in Figure 6. The calibrated upper White River watershed SRM model shows excellent fit during the April-May peak discharge, all base flow periods, and overall the runoff volume for the water year is within three percent.

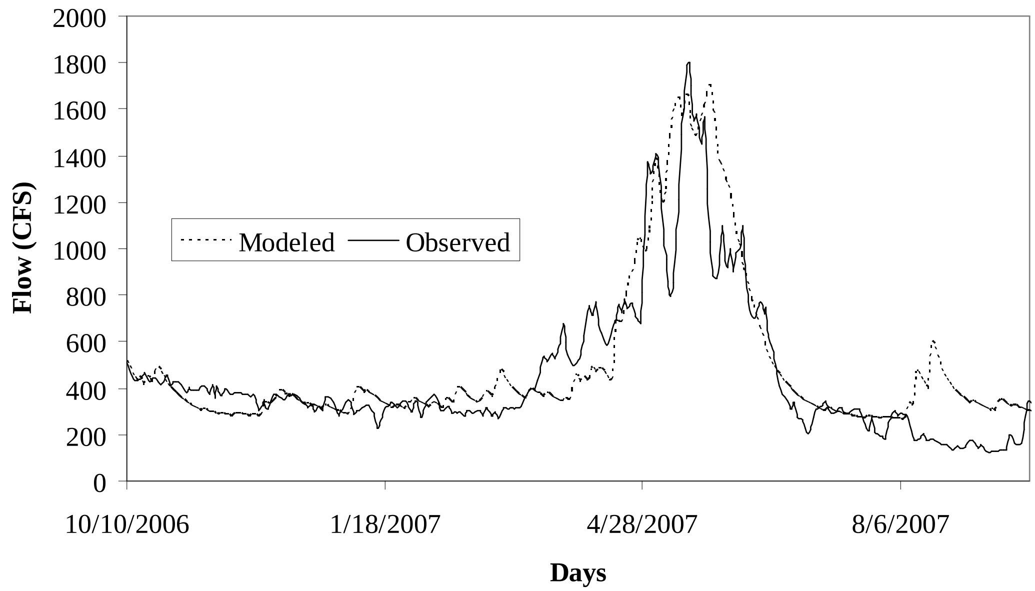

Figure 6. SRM simulated discharge and corresponding streamflow observations (gauge 09034200) for the 2007 water year calibration period

The SRM model was first validated using observations from water year 2006. Validating SRM for different time periods from calibration is challenging because the parameters being adjusted may change with time. Figure 7 displays the results of the water year 2006 validation. Overall, the simulated discharge matched well with the observations. The timing of the peak discharge matches and the total runoff volume is within 13 percent. An additional validation step was performed using the 10-year averages of temperature, precipitation and stream flows rather than a single year (water year 2006 for example). As shown in Figure 8, the validation for the 10-year averages for precipitation, temperature and streamflow shows excellent model performance with timing of peak discharge matching, base flow captured, and the total volume within 6 percent.

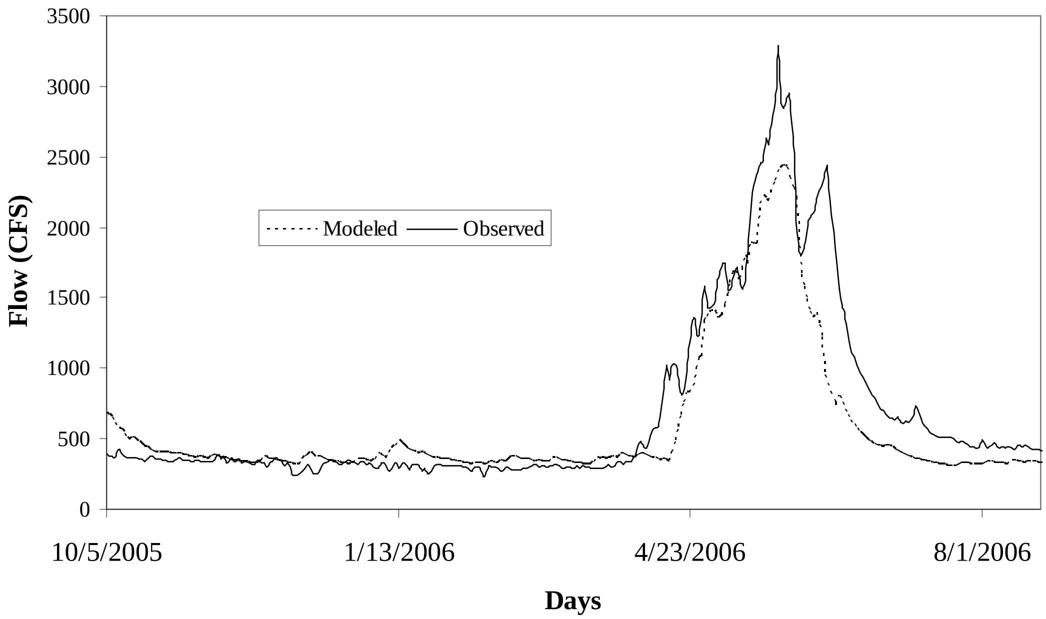

Figure 7. SRM simulated discharge and corresponding streamflow observations (gauge 09034200) for 2006 water year validation period

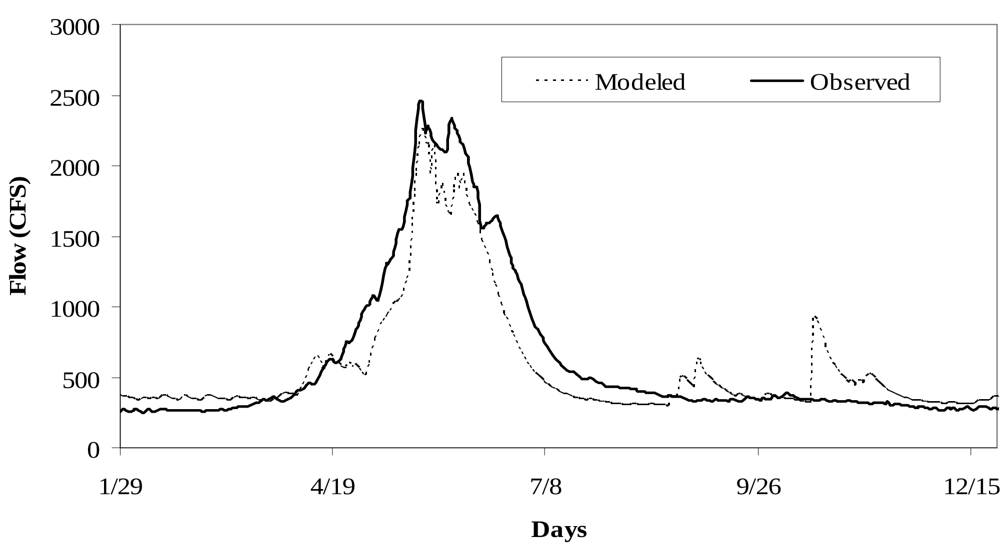

Figure 8. Ten-year validation of snowmelt runoff using average input data

2.2.3 MODSIM-DSS Water Management Model

MODSIM-DSS is a generalized river basin decision support system and network flow model developed at Colorado State University and designed to assist in the management of river basins (Colorado State University, 2009). MODSIM-DSS also has an easy to use graphical user interface (described in Appendix A). The software accepts input of streamflow either from gauge records or simulation and provides the capability to track the water balance in a river-reservoir system accounting for inflow, outflows, losses, and gains of the surface water system.

Streamflow input data acquired from the USGS stream gauge records for gauge 09034200 near Meeker, CO (upstream watershed) and gauge 09306500 near Watson, UT and gauge 0930690 near Ouray, UT, both in the downstream watershed (Figure 2). The USGS flow data was downloaded for 1977 to 2009 as mean daily flow in cubic feet per second (cfs). The discharge records from the Taylor Draw Dam were obtained for the time period January 2003 to December 2008 from the dam operator (Rio Blanco Water Conservancy District). The data were converted from hourly intervals to daily mean discharge values to match the streamflow data and the time increment of modeling.

MODSIM-DSS models were created for both the upstream and downstream segments of the White River corresponding to the upstream and downstream watersheds (Figure 2). The calibration and validation process for both models was performed identically with very similar results; therefore, only the process and results for the downstream watershed is described here. The downstream watershed is the most critical for this study because this is the location of the proposed reservoir that is the focus of the study. Figure 9 illustrates the model elements and connectivity.

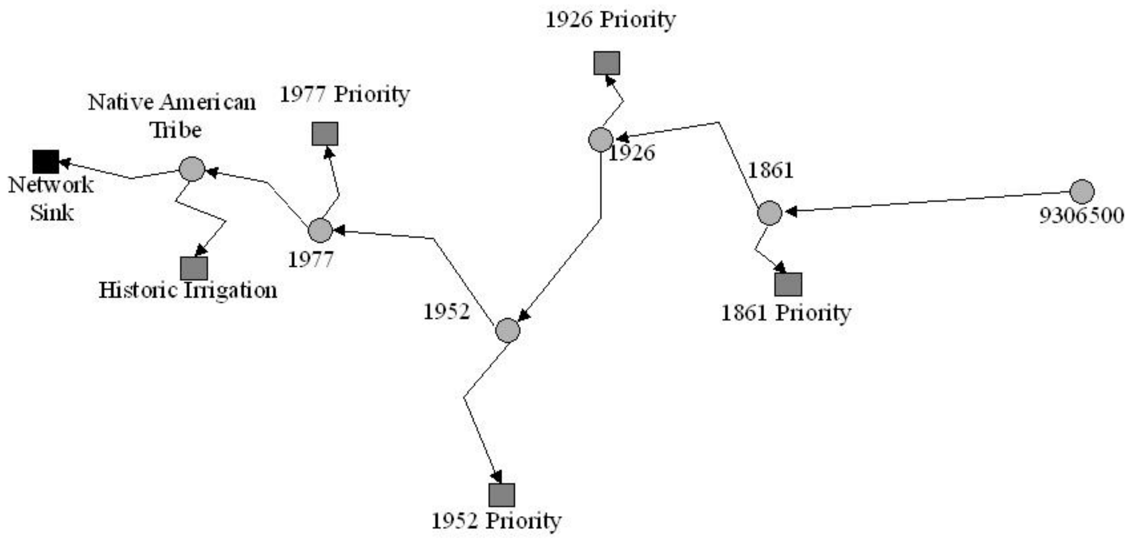

Figure 9. Illustration of the configuration of the downstream segment of the White River system in MODSIM-DSS

Calibration and validation of the downstream MODSIM-DSS model is difficult because the Taylor Draw Dam was constructed in 1992. Data prior to this time period downstream of the reservoir are not representative of current conditions. Time periods before 1992 can use the streamflow records, but periods after 1992 must use the discharge records from the Taylor Draw Dam to represent the upstream boundary. The USGS stream gauge near Ouray, which is just upstream of the White River's confluence with the Green River, represents the downstream boundary in either case. Calibrating this water management model presents two additional problems. First the USGS stream gauge records have small errors and second, water withdraws from the river vary from year to year and even fluctuate during the year. The model is based on "paper" water rights, but those will be different from what is actually extracted. Although these challenges are present the model may still be effectively calibrated and validated for use in this particular study because this study is trying to simulate future conditions and does not require absolute accuracy of current conditions.

It was decided to use data prior to 1992 for the calibration and validation to avoid the Taylor Draw Dam influence. The USGS stream gauge near Ouray (09036900) represents the downstream boundary and the USGS stream gauge near Watson (09306500) represents the upstream boundary (see Figure 9). The calibration of the model was completed using the historic data from both stream gauges. The calibration time period used is from 1/1/1979 to 12/31/1979. The calibration was performed using this year because calendar year 1979 was an average year for stream flows in this basin. Also, the latest valid water right that diverted directly from the river was filed and certificated in 1977. This means all of the rights that are currently valid were valid in 1979.

Due to the great distance between the two stream gauges (over 40 river miles) there is the potential for a great deal of error during rain and snowmelt events that are not timed perfectly by the simulation. The calibration of the water management model is accomplished by adjusting inflows and outflows to the model between the upstream and downstream boundaries until the simulated flows match the observed flows at the downstream stream gauge. The inflows may represent inputs to the system from small streams and other sources and outflows may represent a range of losses including evaporation and seepage, and diversions. Figure 10 displays April to August of the calibration time period, showing the match of the simulated flow and the observed flow from the USGS near Ouray (09036900). April to August is displayed in the figure because this is the time period when there is the largest potential for error in the modeled

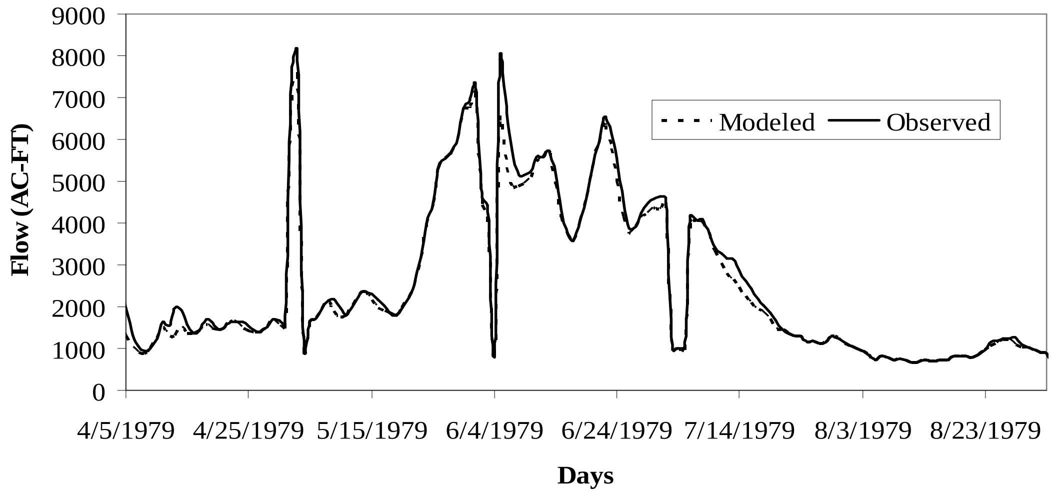

Figure 10. MODSIM simulated flow and corresponding streamflow observations (gauge 09036900) for the April to August 1979 calibration period

river system. This is because peak flows occur during this time period and the greatest amounts of diversions take place during this time period. The simulated flow volume for the entire year is within six percent of the observed flow volume and the timing of the flow during the critical April to August time period matches well. All of the records for the calibrated model were within the +/- 10 percent error. Since the majority of the verified data points fall within the allotted percent error the calibration was successful. Figure 11 displays the resulting net flow adjustments required to achieve the calibration. A few of the adjustments were significant rates for very short periods of time likely representing runoff events not captured in the simulation.

Calendar year 1981 was selected for the validation because it is a below average flow year, which would test the skill of the model in estimating for critical dry periods

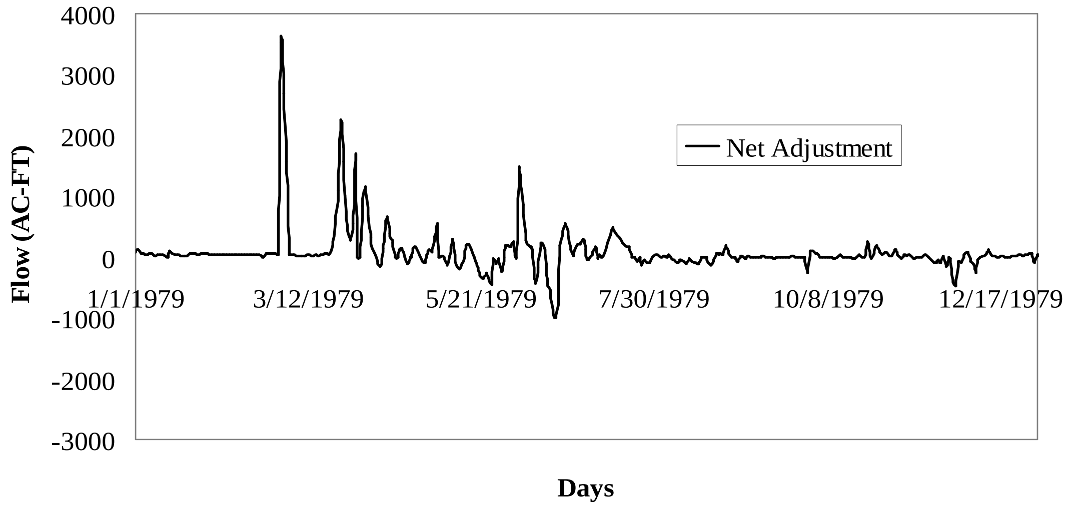

Figure 11. Net calibration adjustments representing losses and gains in the downstream segment of the White River

that will be of interest later in the study. Figure 12 shows the simulated and observed flow rate for the April to August time period. There is a slightly greater difference in the validation when compared to the calibration, but none is significant. Overall, the timing is fine and the total annual volume is within 10 percent. An additional validation was performed for a wet year (1983) and the results are shown in Figure 13. The validation results were better for 1983 (wet year) than 1981 (dry year), which is expected because during wet years less water is diverted and the variability of diversions and losses will be less. In addition to the validation for the dry and wet years an average year (1980) was also tested. The results again showed fairly good comparison of simulated and observed flows. Figure 13 displays a frequency distribution of errors for the three validation years to compare the relative effectiveness of the model for the different conditions wet, dry, and average flow.

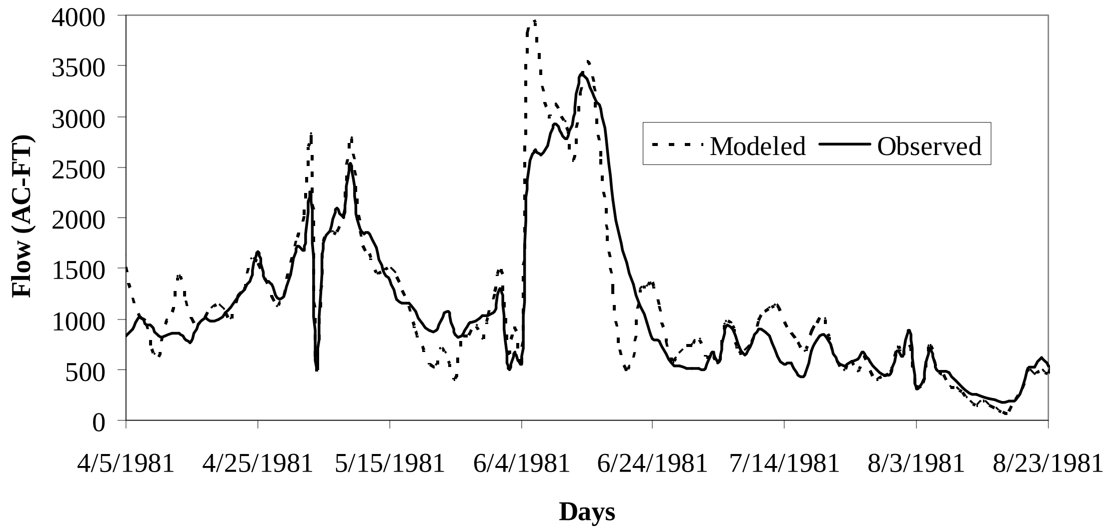

Figure 12. MODSIM simulated for and corresponding streamflow observations (gauge 09036900) for the April to August 1981 validation period

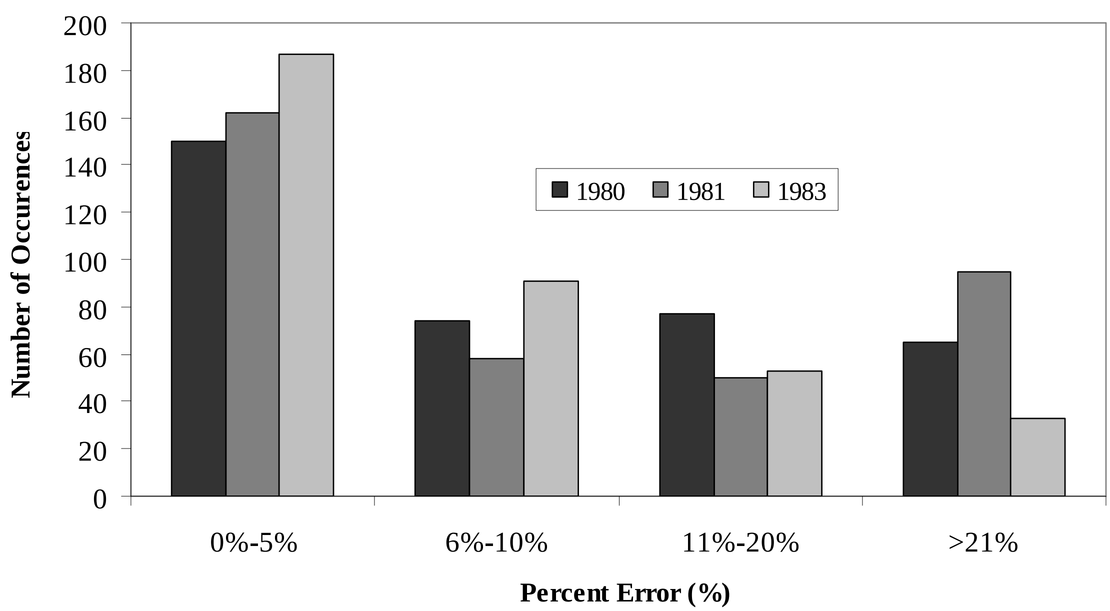

Figure 13. Frequency distribution of percent error of daily volume of flow for the three selected validation periods – a wet year (1983), a dry year (1981), and an average year (1980)

2.2.4 Connecting Upstream to Downstream

The upstream SRM-MODSIM model and the downstream MODSIM model were calibrated separately and need to be combined to perform the simulations for this study. The integrated model is calibrated using data for calendar year 2002 following the same procedure as the calibration for the two independent MODSIM models – adjusting inflows and outflows to account for gains and losses from the river that are not represented in the model. The simulated flow after the model calibration is compared to the observed flow at 09036500 with the results shown in Figure 14. The timing of the simulated flow follows the same pattern as the observed flow, but overestimates the flow consistently with a percent difference in total runoff volume of 26 percent. The net adjustments from the calibration are displayed in Figure 15.

The calibrated model was tested by applying it to simulate the 2001 calendar year. The results from this validation are shown in Figure 16. The validation results look much

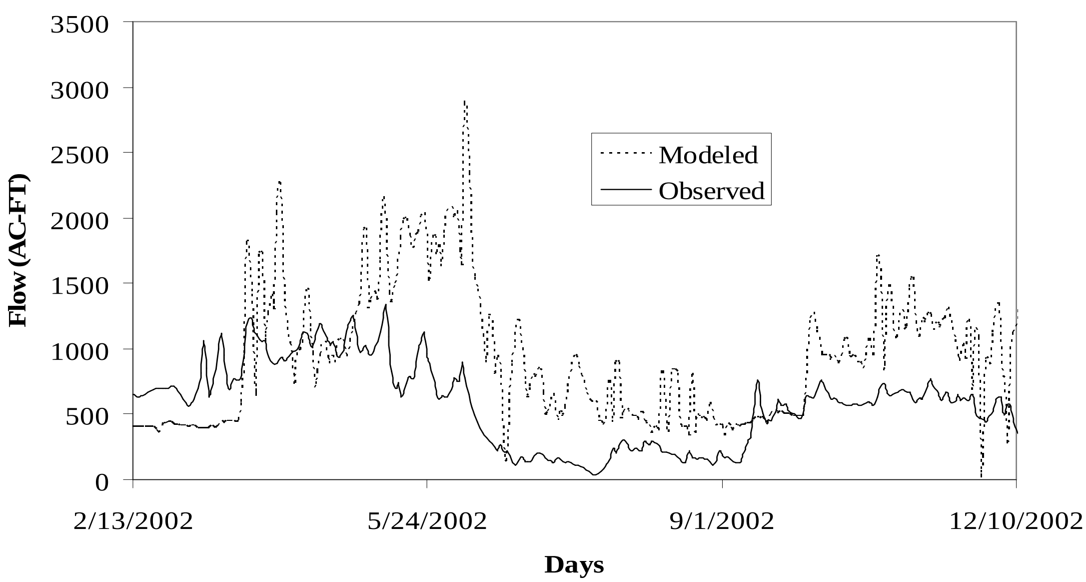

Figure 14. Comparison of simulated and observed flow at 09036500 for the 2002 calibration period using the integrated model

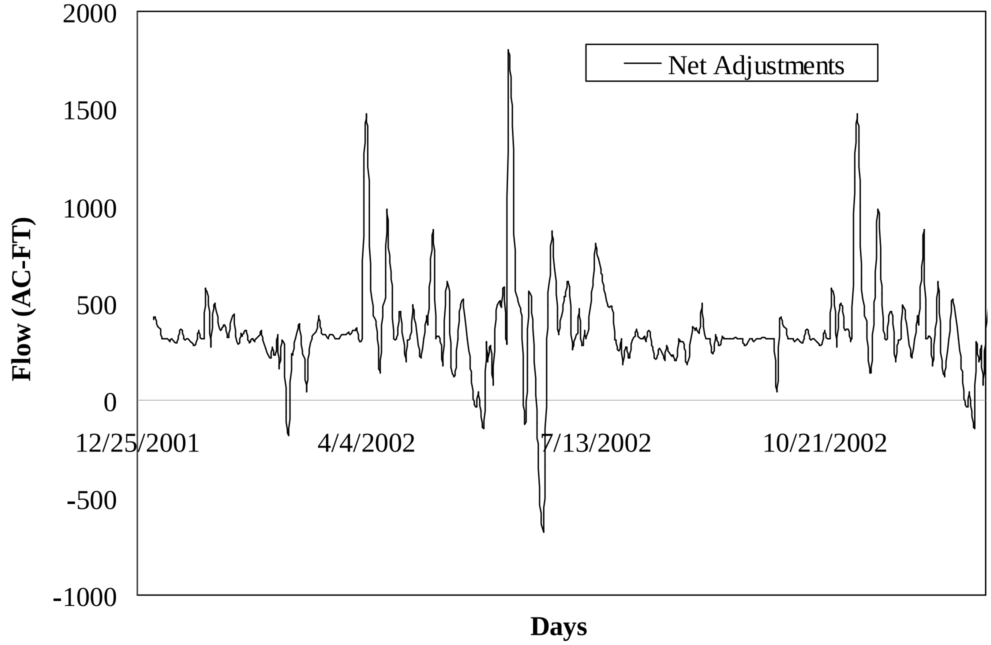

Figure 15. Net adjustments applied to calibrate the model to the 2002 calendar year

better than the calibration with the simulated flow pattern matching very closely the observed. The total volume for the two simulations is within 2 percent.

2.3 Climate Change Analysis

To test the hypothesis of this research the impacts of projected climate change on the proposed White River reservoir is assessed using the integrated SRM-MODSIM model of the White River system. The study involved adjusting the temperature, precipitation, and evaporation according to projected climate change impacts and, first each parameter independently then together. The simulations are performed to quantity the change in reservoir performance. These climate change analyses are carried out for a current water demand and a projected water demand pattern incorporating energy development water requirements.

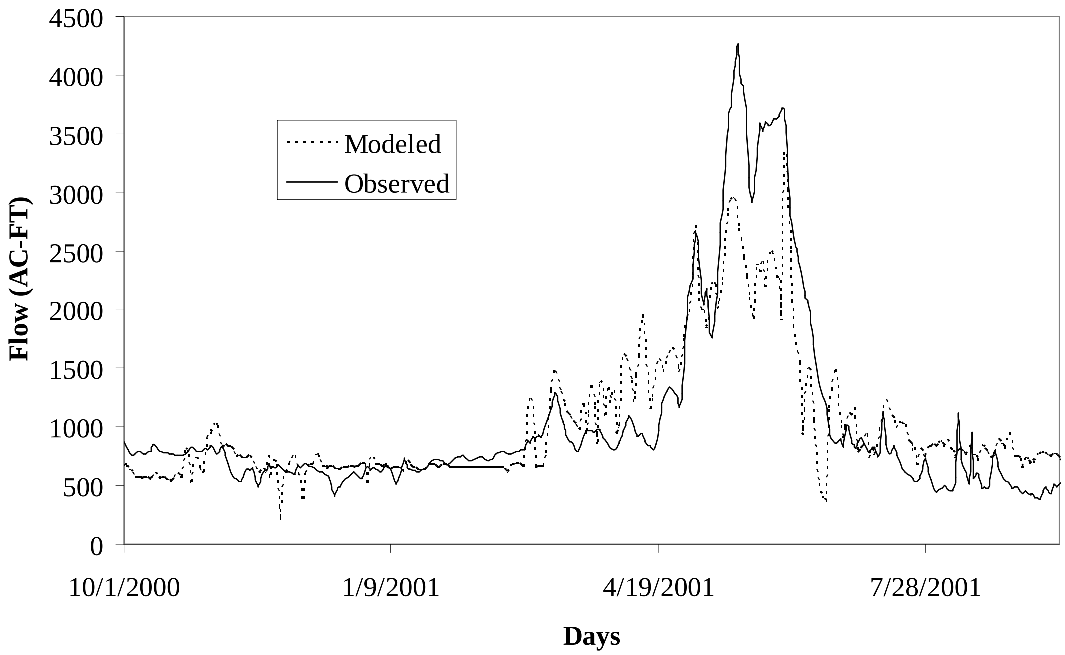

Figure 16. Validation of calibrated flows connecting all three models

2.3.1 Adjusting Precipitation, Temperature, and Evaporation to Represent Climate Change

Precipitation, temperature, and evaporation are key hydrologic processes known to influence the hydrologic response of river systems and performance of reservoirs. The three inputs act conjointly to influence the hydrologic response of a system. For example, altered temperature will cause changes to precipitation and evaporation, which cascade down to the reservoir performance.

2.3.1.1 Temperature Adjustment

The temperature adjustment projected for climate change scenarios in a specific location or region is difficult to quantify because of the uncertainty of the global change modeling forecasts and the challenges to downscale those results to the local level. For this study, recent temperature trends are determined from the literature and used to extrapolate into the future. According to the IPCC, there will be an increase in global mean annual temperatures by 0.8°C to 2.6°C (1.4°F to 4.7°F) by 2050. According to the study done for the Rocky Mountain Region, by the year 2050 there could be a temperature increase of 1.6°C (2.9°F) (Smith et al., 2006). However, the 90 percent confidence range of global warming is in the range of 2°C to 4.5°C (3.6°F to 8.1°F) (Wigley and Raper, 2001). To test the relative impact of climate change effects on the hydrologic cycle versus water demands it was decided for this study to use a high end estimate of the possible temperature change. If the water demand impact on reservoir performance is greater than the high end of the projected climate change effects then the hypothesis of water demands being more important can be confirmed with greater confidence. Therefore, the temperature data from the SNOTEL sites were adjusted to be 4.5°C (8.1°F) higher in the projected time 50 years in the future. This change in temperature is in the 90 percent confidence of all major studies and trend analysis.

2.3.1.2 Precipitation Adjustment

The average annual precipitation values in the future are also projected to change. Depending on the region, precipitation is projected to increase or decrease in annual amount, intensity and frequency. In the American southwest, average annual precipitation is projected to decrease. The continental interiors are also projected to experience a decrease in summer precipitation due to the increase of evaporation (IPCC 2007). Studies have been conducted on a more regional scale for the Rocky Mountain region and according to these studies it has been estimated that with a 1.6°C (2.9°F) temperature increase, the precipitation will decrease by two percent to seven percent (Smith et al., 2006). Some projections suggest precipitation values could increase rather than decreases. However, for this research the critical condition to test is for a decrease in precipitation. The precipitation change incorporated into the study is selected to be the maximum projection found for the Rocky Mountain region – a decrease of 7 percent.

2.3.1.3 Evaporation Adjustment

Under most climate circumstances an increase in temperature will be accompanied by an increase in evaporation and transpiration. However, over the past 50 years, recorded pan evaporation rates have been found to have a decreasing trend, leading to the notion of the pan evaporation paradox (Fu et al., 2007). Nevertheless according to the study by Fu et al. (2007) there are many uncertainties as to how the data was collected. The study implies that while they have seen a decrease in pan evaporation values, this decrease is not universal. Fu et al. (2007) determined that for the Mountainous West, the data that have been collected indicate that there has been an increase in evaporation by roughly 1 percent every 10 years since 1957. This one percent increase in evaporation has been confirmed by other studies stating that regardless of pan evaporation values natural systems have seen an increase in evaporation over the last half of a century (Golubev et al., 2001). Since the simulations for this study are being conducted for a hypothetical climate change condition 50 years in the future evaporation increase was selected to be 5 percent. The evaporation data collected for this study from the Western Regional Climatic Center (WRCC) were adjusted before being entered into the SRM-MODSIM integrated modeling system.

The evaporation adjustment will take into account the building of a new reservoir on the White River. Using the proposed reservoir details a surface area capacity curve will be generated and used in MODSIM to account for evaporation losses. Figure 17 illustrates the elements and connections of the MODSIM model of the lower White River segment with the proposed reservoir inserted. The beginning node of the model is where all flow records, from the SRM, are input and altered to represent the changes in flows experienced during climate change. A second modification to the model is the addition of a future water demand representing requirements to support energy development and associated energy and urban growth needs (see Figure 17).

2.4 Scenarios Description

2.4.1 Overview

To study the impacts of climate change modified precipitation (P), temperature (T), and evaporation (E) on the White River system and to account for the uncertainty of the projections of P, T, and E several scenarios were defined (Table 3). Existing

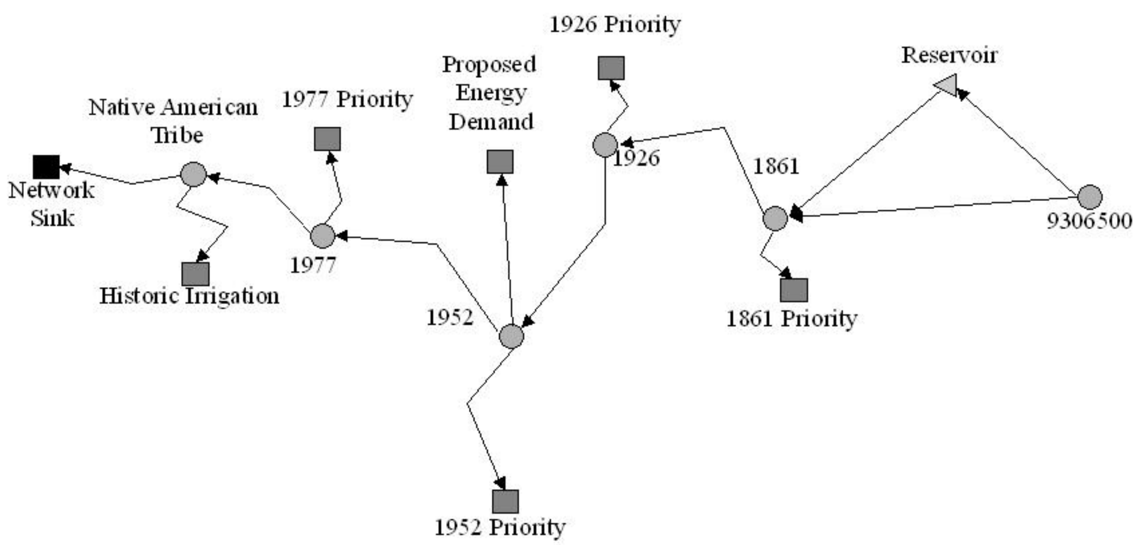

Figure 17. Water management model representing future conditions with reservoir

Table 3. Parameter modifications to simulate climate change

Scenario/ Parameter	Forecasted	Extreme	Armageddon
Temperature	4.5°C increase	9°C increase	13°C increase
Precipitation	7 percent decrease	14 percent decrease	25 percent decrease
Evaporation	5 percent increase	10 percent increase	15 percent increase

conditions are used for the first scenario. Incorporating the P, T, and/or E changes represents scenario two (Forecasted). To hypothetically increase the changes to P, T, and E to further challenge the research hypothesis two additional scenarios were defined. Scenario three (Extreme) incorporates a doubling of the projected climate change impacts on P, T, and E, while scenario four (Armageddon) incorporates nearly a tripling of the projected climate change impacts. The changes to P and T are made to the SRM model, while the change in E is only made in the MODSIM model.

In order to mimic what is happening in a warmer year, it is necessary to change the runoff coefficients in SRM. This is done to try and show how soil moisture changes when the temperatures are warmer. Studies have shown that with an increase in temperature there would be less runoff, in particular rainfall runoff, because the soil water demand is higher in warmer years (Yang et al, 2003). The runoff coefficients, which tell the model how much water is needed before runoff can occur, were changed incrementally along with each of the scenarios to represent a higher soil water demand.

The adjustments will be a blanket adjustment for the entire simulation period for each parameter. An analysis was performed by changing only certain data ranges; however, due to the setup of the model, the difference in the results were negligible. Therefore, since a blanket adjustment is more easily performed this method was chosen. A 10-year average will be used for the temperature parameter increasing each day of the record by the specified amount. Also with an increase in temperature the model needs to know that the melt season will begin sooner. This is changed by altering the degree day factor in the model. Since precipitation falls sporadically every year, the percent reduction is applied to each year and then a 10-year average is taken of the modeled output. The evaporation is a 10-year average of the data collected by the WRCC and is applied only to the new proposed reservoir. Evaporation from the river is accounted for in the calibration of the MODSIM model.

With a reservoir on the river there is the potential of additional water users to come into the area. The proposed future water uses on the river are for different forms of energy development. A reasonable range for future energy water demands from the energy development industry, energy generation industry and urban growth sectors is 55 AC-FT/day to 400 AC-FT/day (Burian et al., 2009), as presented in more detail in Appendix A. The average of the projected amount will be input into the model (228 AC-FT/day) to represent a reasonable future water condition.

The study is carried out by first incorporating the P, T, and E changes independently. Although not likely to occur given the interconnectedness of these meteorological variables, the exercise was performed to see which would produce the greatest change in reservoir performance. The next step was to analyze the effects of the changes to P, T, and E being implemented in a single simulation, called the “combined” simulation. These combinations of adjustments for P, T, and E were performed for the four scenarios (Table 3). All four scenarios (including the variation in P, T, and E) were each simulated for existing water demand conditions and future water demand conditions.

Analysis of the SRM-MODSIM simulation results is performed to assess the relative changes to hydrologic variables and, most importantly for this study, the impacts on reservoir performance. For this study, the reservoir performance is considered in terms of its functionality based on whether it is able to meet downstream water demands. Thresholds of reservoir storage are set to define functionality (Figure 18). The minimum reservoir storage to maintain functionality is 38,000 ac-ft. If the simulated reservoir storage is at this minimal capacity then the reservoir is classified as Nonfunctional. If the reservoir storage is between 38,000 ac-ft and 77,000 ac-ft the reservoir is classified as Semifunctional. Within this range, the early priority rights are being met and some of the newer rights are not being fully satisfied. If the simulated reservoir storage is above 77,000 ac-ft the reservoir is considered Fully Functional because all of the water rights allocations are being met.

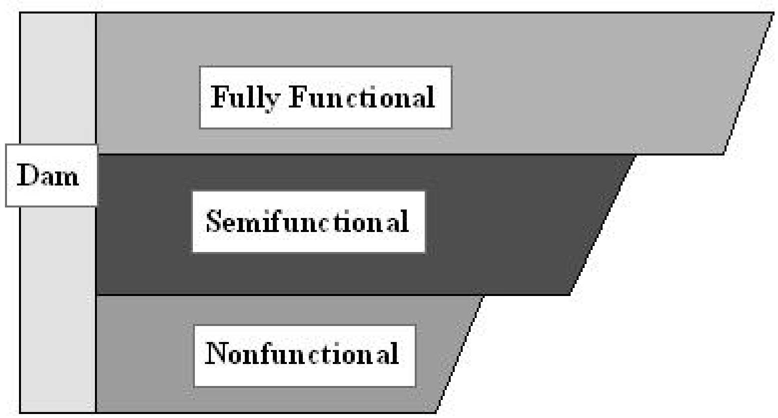

Figure 18. Three reservoir performance ranges based on storage ranges

CHAPTER 3

RESULTS AND DISCUSSION

The average annual SRM discharge results based on the ten year study period are shown in Table 4. The results indicate the increases in T and reductions in P will as expected reduce the discharge. The magnitude of the decreased discharge is significant with maximum percent changed ranging from 16 to 35 percent. T was also found to greatly influence the timing of the runoff, while as shown in Table 4, P influences runoff volume more. When the T and P adjustments are made in SRM at the same time an unexpected result is noted in Table 4 with an lower than expected decrease (note the combined condition of the Forecasted Scenario is larger than the T or E conditions). The reason for this is due to the runoff coefficient changes that are made in SRM to represent the altered temperature. These parameters are adjusted using best judgment, but consistency is lost. Overall, the decreased discharge volume magnitudes are similar to those found in other studies. Chiew et al. (2002), for example, studied discharge changes to P and T adjustments in Australia and found decreased volumes ranging from 5 to 25 percent. Their adjustments (T increase of 1.3°C without a change in precipitation or evaporation) were less than those used in the present study. Another study by Nijsseen et al. (2001) changed T by 2°C and P by 10 percent and found annual streamflow volume to decline by magnitudes similar to what was found in this research. More detailed results are included in Appendix B and recall E for this study is included in the MODSIM

Table 4. Ten-year average showing the effect of climate change on snowmelt runoff volume and percent change from existing conditions

Scenario/ Parameter	Existing Conditions (AC-FT)	Forecasted Conditions (AC-FT)	Extreme Conditions (AC-FT)	Armageddon (AC-FT)
Temperature	177,000	171,000	165,500	127,000
Precipitation	177,000	162,000	158,000	148,000
Combined	177,000	165,000	155,000	115,000
Scenario/ Parameter	Existing Conditions (AC-FT)	Forecasted Conditions (%Change)	Extreme Conditions (%Change)	Armageddon (%Change)
Temperature	177,000	-3	-7	-28
Precipitation	177,000	-8	-11	-16
Combined	177,000	-7	-12	-35

component of the simulation and its effects on the reservoir performance is described below.

The MODSIM simulation was executed for a ten year period from WY1999 (10/1/1998) to WY2008 (9/30/2008). The reservoir fills relatively quickly, in less than four years permitting the 10-year duration corresponding to available streamflow and meteorological data to be used for the study. Once the reservoir is filled, in the Existing Conditions Scenario, reservoir performance is always Fully Functional for the existing water demands (Figures 19 and 20). For the future water demand conditions, the reservoir still maintains Fully Functional status throughout the simulation period. Even under a future water demand at the high end of the projections (see Appendix A) the reservoir performance is mostly Fully Functional with a few short duration periods in the Semi-Functional Classification. The reservoir performance will be acceptable given future water demand requirements.

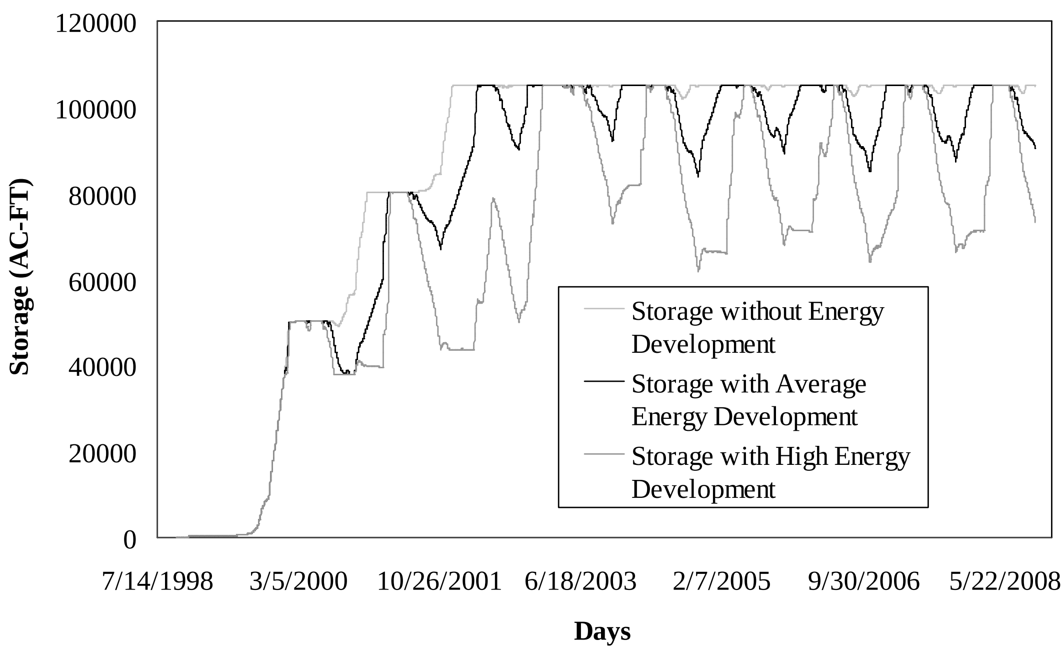

Figure 19. Simulated reservoir storage over the 10-year study period for the Existing Conditions Scenario

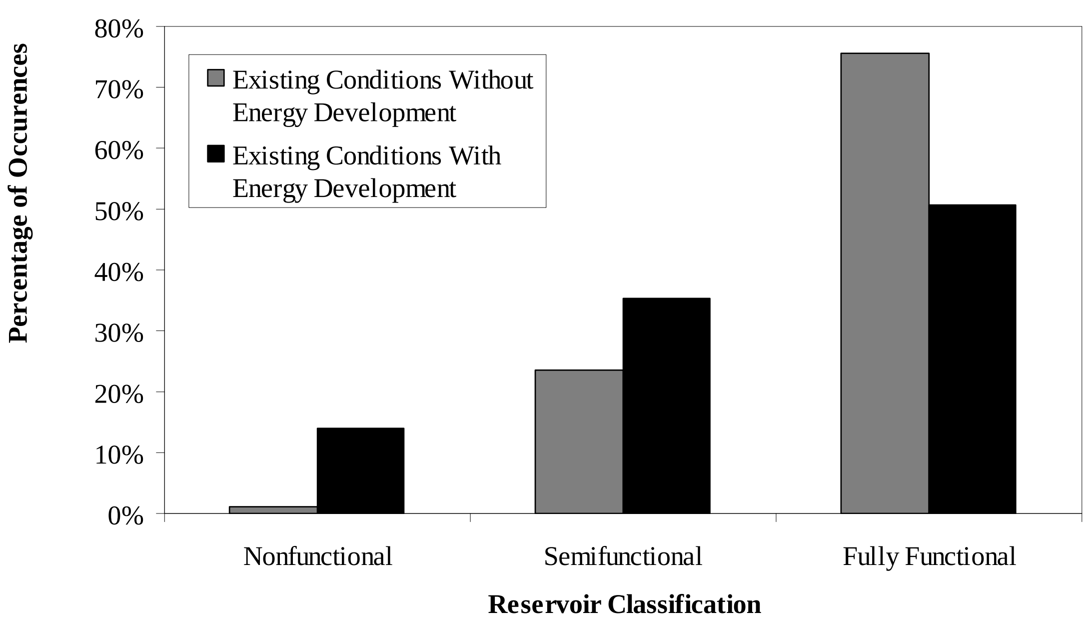

Figure 20. Existing stream conditions showing how the reservoir operates after it was full

The first analysis was to incorporate the three changes to E corresponding to the three Climate Change Scenarios. Figure 21 displays the results for the E changes under existing water demand conditions and Figure 22 displays the results under future water demand conditions.

Under existing water demand conditions, there is minimal effect of E on the functional performance of the reservoir. Under future water demand conditions, the reservoir storage classification of Fully Function is reduced by more than 20 percent, with more of the simulation period being classified as Semifunctional. Similar results were found for the P and T adjustments made independently and they are presented in Appendix B. Figures 23 and 24 display the results for the combined changes to P, T, and E being incorporated into the model with Figure 23 representing existing water demand conditions and Figure 24 representing future water demand conditions.

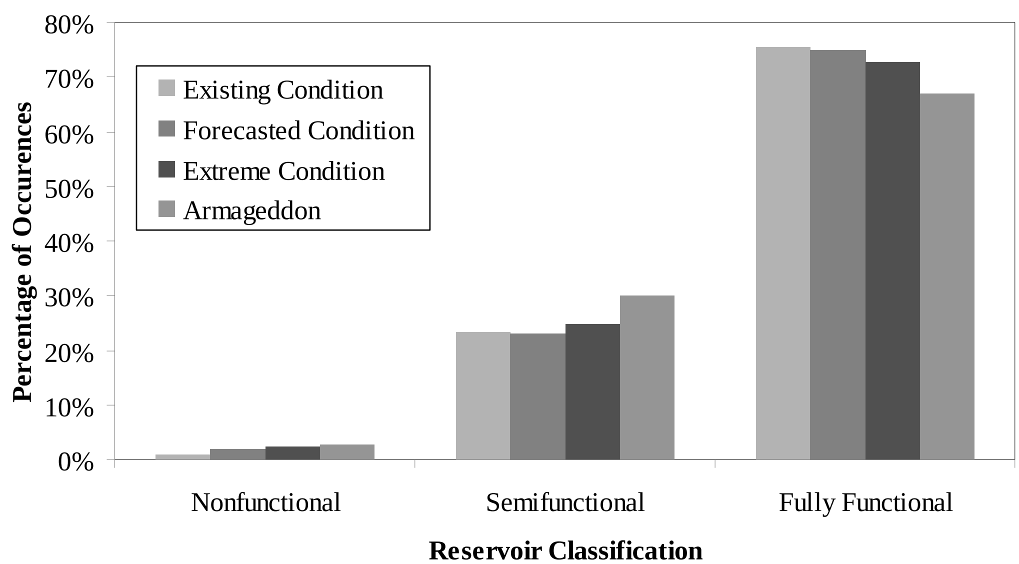

Figure 21 Simulated reservoir storage classification for the four Evaporation Scenarios under existing water demand conditions

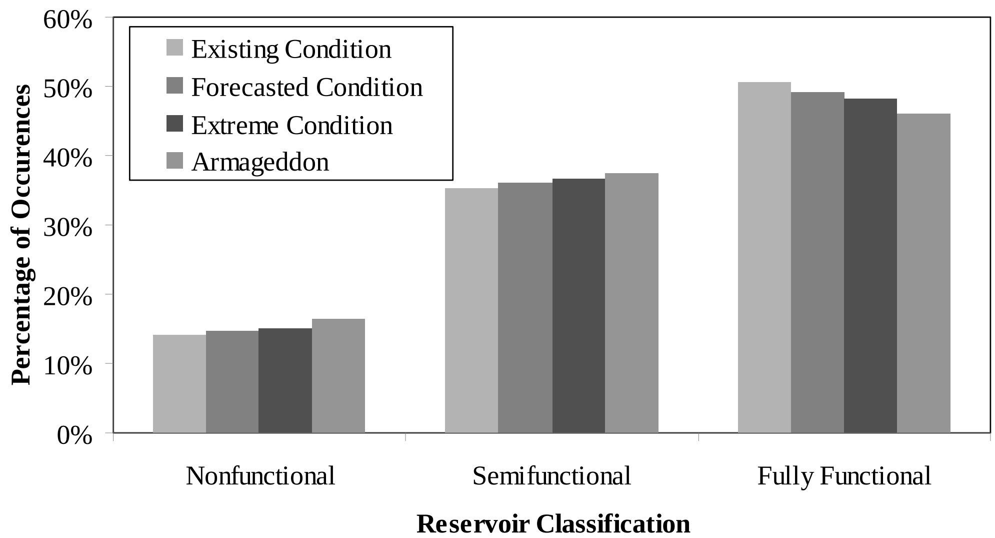

Figure 22 Simulated reservoir storage classification for the four Evaporation Scenarios under future water demand conditions

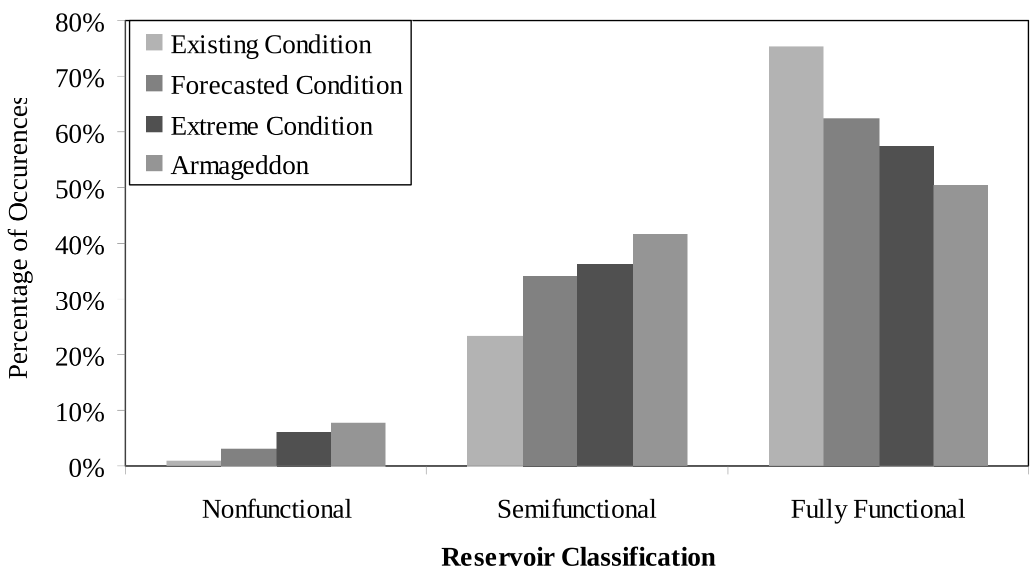

Figure 23 Simulated reservoir storage classification for the four Combined P, T, and E adjustment Scenarios under existing water demand conditions

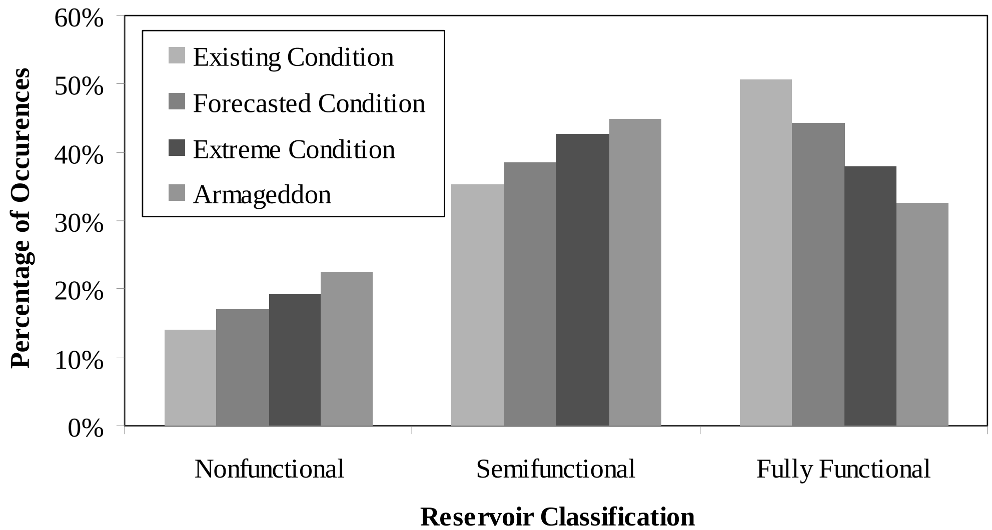

Figure 24 Simulated reservoir storage classification for the four Combined P, T, and E adjustment Scenarios under future water demand conditions

The results again show that an increase in water demand has a greater affect on the simulated reservoir functionality than do the changes to P, T, and E representing climate change scenarios. In the combined adjustments simulation under the existing water demand conditions the reservoir maintains Fully Functional classification for both the Forecasted and the Extreme Scenario, but not the Armageddon Scenario. Under future water demand conditions, the simulated reservoir functionality is classified for the majority of the time as Semifunctional or Nonfunctional for the three climate change scenarios.

The results presented can be analyzed in terms of the percent change in reservoir classification. Figure 25 shows the relative changes to simulated reservoir functionality from existing conditions, to climate change only conditions, and to the climate change conditions plus future water demands. The results indicate the relative importance of future water demands with the changes in reservoir functionality occurring predominantly from the inclusion of the future water demands.

Another consideration not included in this study is the impact of climate change on other areas of water demand including crops and livestock located in the study area. If these demands increase, the White River System may be targeted for further water demands.

A quick analysis was performed by increasing the current irrigation season (April 1 to October 31) to a hypothetical longer duration (March 1 to November 30). The longer irrigation season represents a 25 percent increase for irrigation demands. To maintain a level of consistency, the other water demands were also increased by 25 percent and the future water demand for energy development was arbitrarily increased by 10 percent. Simulations were performed for each scenario. The results from these simulations show similar results to the combined scenario shown in Figure 25. The reservoir storage is classified as Fully Functional under existing conditions; however, in the other scenarios the simulated reservoir storage classification is only Semi-Functional with or without energy development (Figure 26).

The sensitivity of the reservoir's feasibility increases with the increase of water demands. For the existing conditions the reservoir is classified Fully Functional 45 percent of the time with the increase of water demands. In the Forecasted Scenario the reservoir storage is classified as Semifunctional 54 percent of the time, which means that not all of the water demands are being met on the river system.

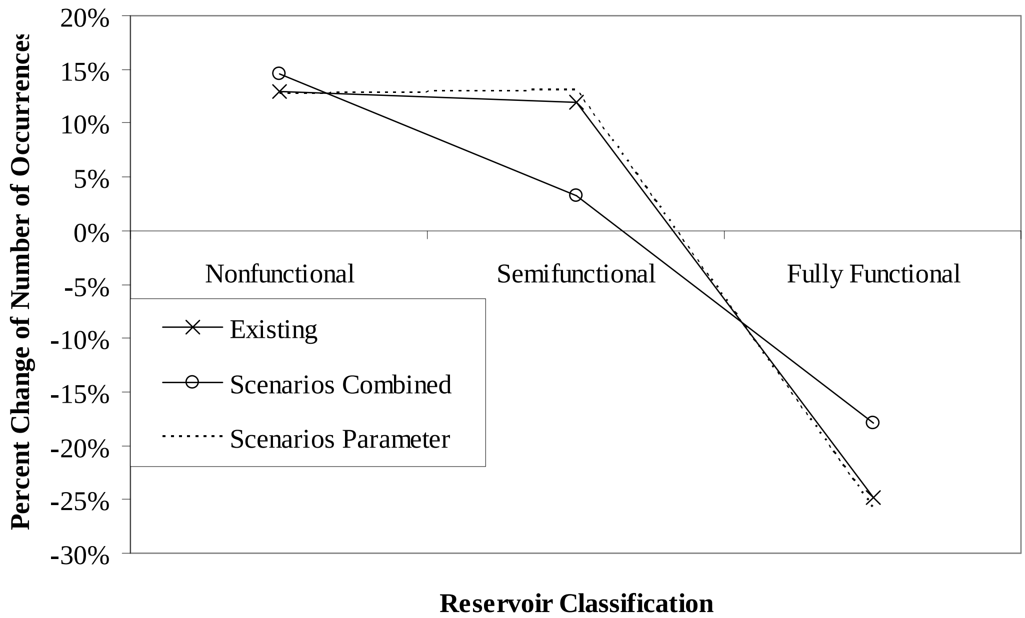

Figure 25. Sensitivity of simulated reservoir storage classification to changes in P, T, E (scenarios parameter) and changes to future water demand plus climate change scenarios (Scenarios Combined)

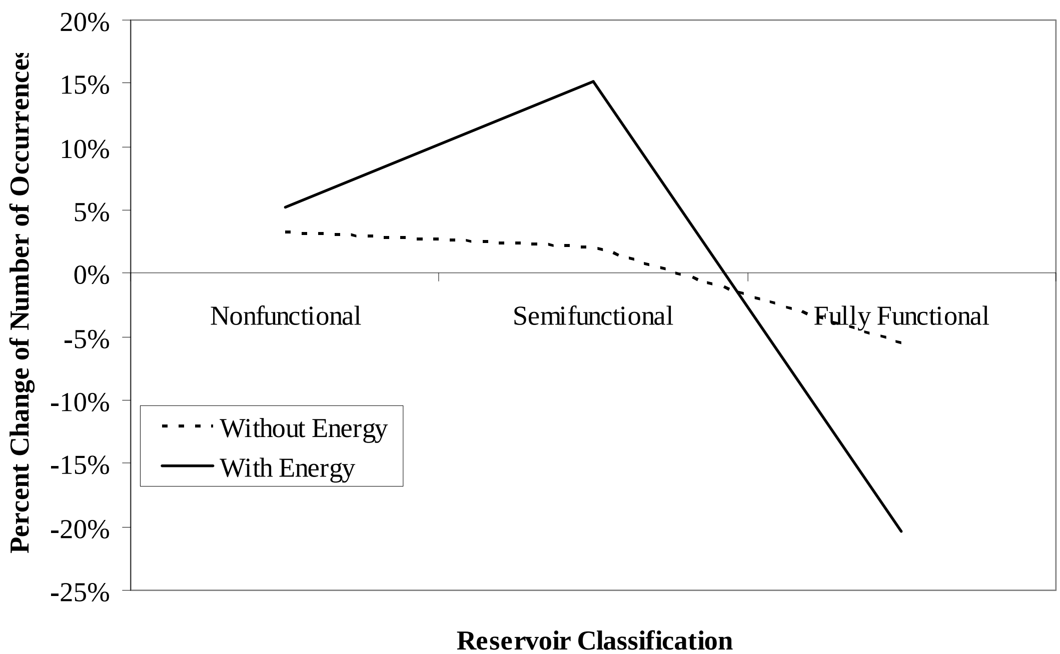

Figure 26. Sensitivity of simulated reservoir storage classification to changes in P, T, E (scenarios parameter) and changes to future water demand plus climate change scenarios (Scenarios Combined)

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

Climate change is occurring; the global temperature is rising due to the collection of greenhouse gases in the atmosphere. The hydrologic cycle is being altered due to this change in climate. This research modeled the effects of a changed climate using snowmelt runoff and water management models. The models used data collected to emulate existing conditions. Once the existing conditions were modeled adjustments were made to the modeled parameters to demonstrate the sensitivity of (1) snowmelt runoff and (2) a reservoir with respect to climate change.

An analysis was performed for each parameter (temperature, precipitation, or evaporation) by changing each parameter by a specified amount. The parameters were altered based on forecasted conditions and two other scenarios (Extreme and Armageddon) to determine how sensitive the model is to each parameter. The additional scenarios took the forecasted conditions and augmented the change by doubling and tripling the parameter change, respectively. Once each individual parameter was altered and modeled they were combined into one simulation to show the effects of climate change on the hydrologic cycle. The final simulation performed investigated the effect of an increase in water demands.

Once the results were generated the hypothesis of evaporation having the greatest effect on the reservoir functionality was proven to be incorrect. Precipitation proved to generate the largest water loss on an individual parameter level. This in turn had the greatest affect on reservoir functionality. However, the differences between each individual parameter were small. The combined climate change scenario did impact the reservoir however the increased water demand had a greater effect on reservoir feasibility. Therefore, this hypothesis was proven to be true by the modeled results.

There are a few datasets that would be conducive to more accurate models and therefore more accurate results. The first dataset that would beneficial to a future climate change investigation would be soil moisture data. This would enable the researcher to understand more fully how the runoff changes with the temperature. Since it is hypothesized, by other researchers, that soil and plants will require more water in a warmer climate soil moisture data will provide a better understanding of how soil moisture changes with the climate. The second dataset that could use improvement, for this study and other studies of this nature, is stream gauge information. With more accurate stream gauge data a more accurate calibration and validation could be performed. More accurate datasets would alter the methods of this research slightly; however, the general methods used in this research should be followed for similar reservoir feasibility studies.

Finally with any research it is important to be able to take the methods and apply them to more than one study area. With this research this can easily be accomplished. As described in this research the necessary datasets are stream gauge data, SNOTEL datasets and water demand information for the given study area. Any area in the Western US will have these pertinent datasets. To research the climate change effects on an area that has snowmelt generated stream flow it would be necessary to know the area of the contributing watershed and when the snow melts. Then an analysis can be performed on how climate change could theoretically affect that specific watershed. In addition to the ability of mimicking the snowmelt runoff it is possible to determine reservoir feasibility directly downstream of where the snowmelt runoff is occurring. This can be accomplished using the same methods previously described in this research.

In conclusion, constructing a reservoir requires the understanding of how climate change could potentially affect flows that provide the water for the reservoir. If the altered hydrology cannot support a reservoir then the reservoir is not feasible. In this study, the reservoir is feasible in the forecasted scenario without the proposed energy demands on the water. With increased water demands the reservoir is classified as semi-functional for all climate change scenarios. If the climate changes more drastically than what has been forecasted, then the reservoir is no longer feasible, regardless of energy development. The reservoir should only be built if energy development will take place. This is because, for this particular area there would not be a valid economic reason to build the reservoir unless energy development occurred. Also the duration of the energy development needs to be considered prior to construction of the reservoir. If the oil shale companies only develop oil from shale for short periods of time the reservoir usefulness needs to be reconsidered. In order to build the reservoir there needs to be assurances that water will be provided to energy developers and the energy developers would need to agree to develop energy as long as there is water. Using this agreement the reservoir would be both useful and economically feasible.

The last item to consider prior to determining the feasibility of the reservoir is the quantity of oil being extracted. The value used in the simulation was an average amount.

If it is shown that oil development is feasible but needs to be done at a rate higher than what is specified in this report (228 AC-FT/day) the reservoir feasibility will be affected. It was proven in the results that energy development at a higher rate (400 AC-FT/day), under existing conditions, shows that the reservoir is fully functional. However, under the climate change scenarios, with a higher water demand, the reservoir classification would change to semi-functional or potentially nonfunctional. Therefore it is recommended that if the reservoir is built that the management of the reservoir be a top priority to ensure effective water distribution.

APPENDIX A

METHODS DETAILS

A.1 Water Requirements for Energy Development

Energy development tables for oil shale production in the Uintah Basin synthesized and re-created for this section of the report (Table 5). Complete tables can be found in the report by Burian et al. (2009).

A.2 MODSIM

MODSIM-DSS is a generalized computer model that has an easy to use graphical user interface (GUI) that allows the construction of a complex river system (Figure 25). Once the basics are understood on how to develop a model using MODSIM-DSS the process is simple. The most important aspect of this software program is to make sure that the data that is being inputted is in the correct units. Since MODSIM-DSS is a Windows friendly software it is possible to copy and paste data into the appropriate data fields. Once all of the data is entered into the model there is only one equation that generates all outputs for the model. A – B = C where A = to inputs/stream flow, B = to outputs/water demands and C = results/downstream flow.

Table 5. Synthesized results table showing water demands for energy development

Oil Shale Production Rate (MBbl/day)	Base Scenario (MAF)	Revised Population Projection Scenario (MAF)	Sustainable Urban Development Scenario (MAF)	Oil Shale Extraction Technology Advances Scenario (MAF)	Alternative Electric Energy Generation Scenario (MAF)	Optimistic Scenario (MAF)	Realistic Scenario (MAF)
0.5	0.04 to 0.09	0.03 to 0.08	0.03 to 0.08	0.02	0.04 to 0.09	0.002	0.03
1	0.08 to 0.17	0.06 to 0.16	0.06 to 0.16	0.03	0.07 to 0.17	0.005	0.05
2.5	0.19 to 0.43	0.15 to 0.40	0.15 to 0.40	0.07	0.18 to 0.42	0.012	0.12

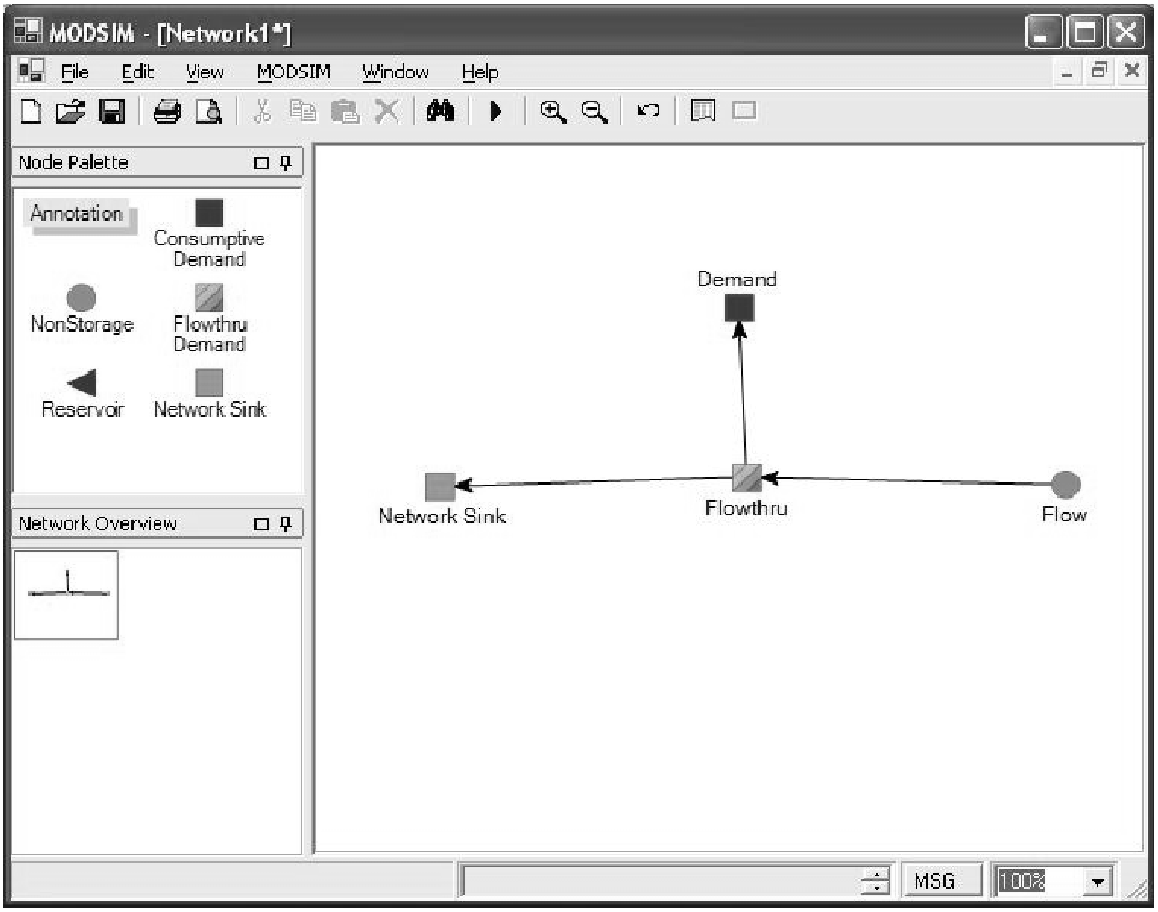

Figure 27. The MODSIM-DSS user interface used to create the water management model

It is the understanding of this simple equation that allows for a quick and easy calibration. When two stream gauges are known, upstream and downstream, then the user inputs the upstream gauge and uses the downstream gauge as the calibrator. Then the net adjustments are added into the equation so a calibrated model equation looks like (A + Adjustments) – B = C. Where the variables equal the same as before and the adjustments equal the results minus the observed downstream flow. Therefore the new C value will more accurately represent the actual stream flow. The final step that takes place in the calibration is reviewing the net adjustments and ensuring that they are within an acceptable range of adjustment. Every stream gauge, which is operated by the USGS, has a classification rating showing how good the stream gauge measurements are. Associated with this rating is a +/- percentage. This indicates that every data point could be +/- that percent. Therefore the net adjustments should not exceed that percent. This ensures accuracy of the inputted dataset.

A.3 Snowmelt Runoff Model (SRM)

The Snowmelt Runoff Model (SRM) can be applied to a wide range of basin sizes (0.76 to 917,444 km^2) and any of the world's elevation ranges (Martinec et al., 2007). The SRM has an easy to use GUI that allows beginners to input necessary model data and generate snowmelt runoff (Figure 26). Since the development of the SRM in 1975 the software has been used by many institutions, agencies and individuals who want to forecast snowmelt runoff. More recently the SRM has been used to understand the affects of climate change on runoff.

Several datasets are required for this model, for most areas in the Western US these datasets can be collected through the Natural Resources Conservation Service (NRCS). These datasets include temperature, precipitation and snowmelt runoff depletion curves. Like MODSIM-DSS this version of SRM is interfaced with Windows and data entry can be done through a copy and paste method. Once the data are entered it can be edited with Edit basin variables or parameters. Selecting the proper period of record changes can be made to the parameters for an individual zone of the entire basin (Figure 27). Behind the user interface is a simple equation that generates the output for a given day. The equation and parameter descriptions are shown below. As stated in the body of this research the equation generates a flow value for each day and for each zone then

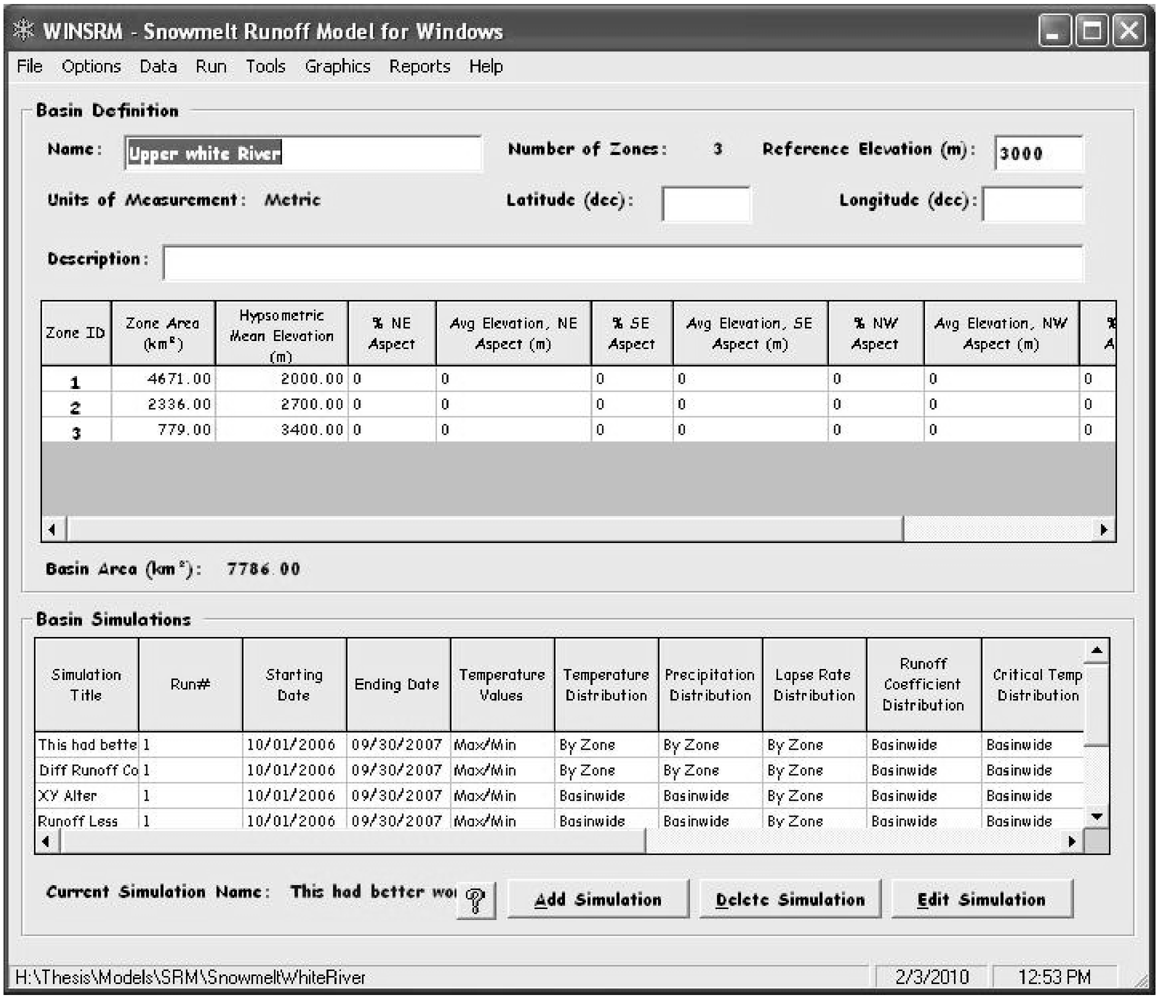

Figure 28. User interface for SRM software

sums those values. The summation of these values is the generated output from the model.

The following table shows the collected data from a SNOTEL site that was inputted into the snowmelt model (Table 6). The snow pillow data are used to determine the melt rate for a given zone. The other data have been collected and adjusted by the Natural Resources Conservation Service (NRCS) in order to more accurately represent the sample area.

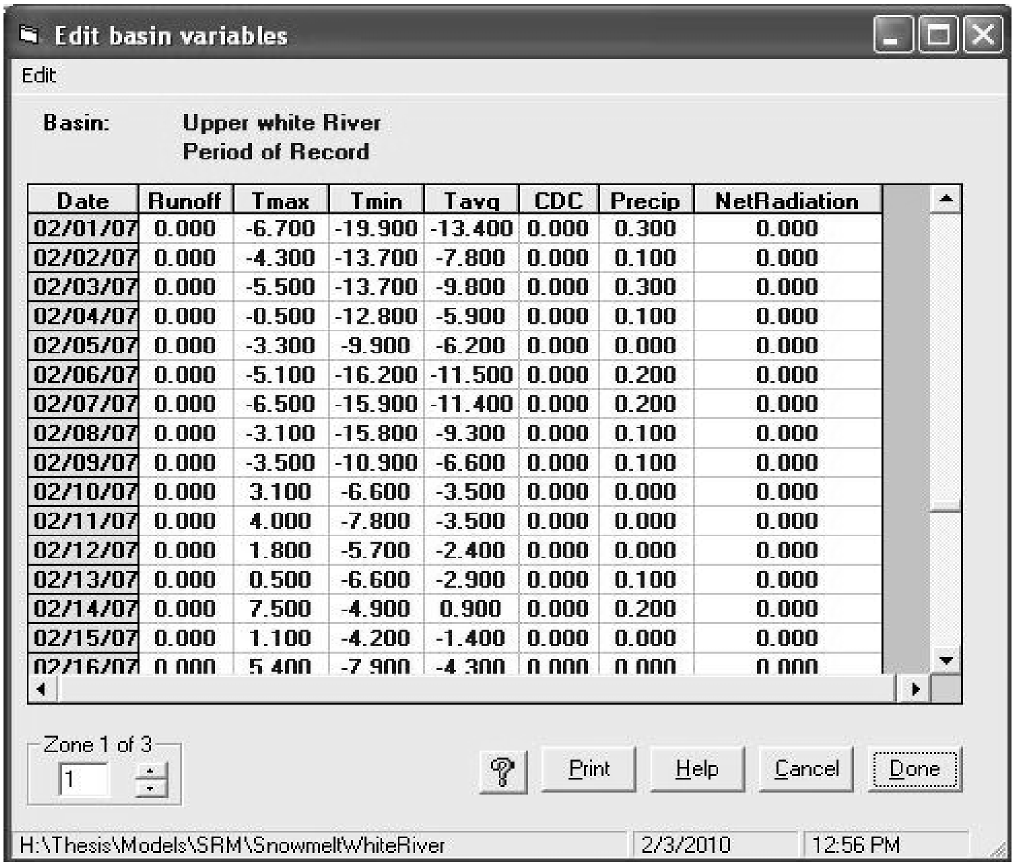

Figure 29. Screen shot of the variables being edited

$$\mathbf{Q_{n+1} = [cS_n \cdot \mathit{a}_n (T_n + \Delta T_n) S_n + c_{Rn} P_n] (A*10000/86400)(1-k_n+1) + Q_n k_n+1}$$

where:

Q = average daily discharge [m^3s^{-1}]

c = runoff coefficient expressing the losses as a ratio (runoff/precipitation), with c_S referring to snowmelt and c_R to rain

a = degree-day factor [cm $^oC^{-1}d^{-1}$] indicating the snowmelt depth resulting from 1 degree-day

T = number of degree-days [^{o}C d]

ΔT = the adjustment by temperature lapse rate when extrapolating the temperature from the station to the average hypsometric elevation of the basin or zone [^{o}C d]

S = ratio of the snow covered area to the total area

P = precipitation contributing to runoff [cm]. A preselected threshold temperature, T_{CRIT}, determines whether this contribution is rainfall and immediate. If precipitation is determined by T_{CRIT} to be new snow, it is kept on storage over the hitherto snow free area until melting conditions occur.

A = area of the basin or zone [km^2]

k = recession coefficient indicating the decline of discharge in a period without snowmelt or rainfall:

n = sequence of days during the discharge computation period.

Table 6. Example of data inputs for Zone 3 in the SRM software

COLORADO BISON LAKE

Date	Snowpillow	Snowpillow (%)	Temp max (C)	Temp min (C)	Temp avg (C)	Precipitation (mm)
1-Oct	0	0	4.1	-6.9	-0.4	1.4
2-Oct	1	3	9.9	-1	2.9	0
16-May	34.4	100	2.9	-7.3	-1.3	0.2
17-May	34.4	100	4.5	-4.7	-1	0
18-May	34.4	100	7.8	-3.1	2.5	0.1
19-May	34.3	100	11	0.7	5.6	0
20-May	34	99	12	3.9	8.3	0
21-May	33.5	97	12.9	5.9	9.3	0
22-May	32.8	95	15	5.2	9.4	0.1
23-May	32.2	94	12.5	-0.3	5.5	0.1
24-May	32.2	94	4	-3.2	-0.2	0.1
25-May	32.2	94	5.4	-3.8	-0.8	0.2
26-May	32.5	94	3.8	-5	-1.1	0.1
27-May	32.2	94	8.1	-2.5	3.3	0
28-May	31.8	92	9.1	-1.8	4	0
29-May	31.4	91	9.3	-2.1	4.1	0.1
30-May	30.1	88	12.2	1.2	6.6	0
31-May	30	87	9.1	0.8	4.7	0

APPENDIX B

RESULT TABLES

The tables in this section show the computed results for every year from the snowmelt runoff model (Tables 7 – 9).

Table 7. Temperature scenario results for each year

Scenario	Existing Conditions (AC-FT)	Forecasted Conditions (AC-FT)	Extreme Conditions (AC-FT)	Armageddon (AC-FT)
1999	191,000	177,000	166,000	131,500
2000	206,500	188,000	176,000	138,500
2001	197,500	185,500	168,000	129,500
2002	157,000	154,500	147,000	117,000
2003	204,000	195,000	182,000	142,000
2004	170,500	162,000	151,500	118,000
2005	196,000	182,000	169,000	132,500
2006	176,000	170,000	159,000	125,000
2007	198,500	181,000	162,000	117,500
2008	206,000	170,000	160,000	119,000
Average	177,000	171,000	165,500	127,000

Table 8. Precipitation scenario results for each year

Scenario	Existing Conditions (AC-FT)	Forecasted Conditions (AC-FT)	Extreme Conditions (AC-FT)	Armageddon (AC-FT)
1999	191,000	166,000	158,000	146,000
2000	206,500	181,000	174,000	163,000
2001	197,500	173,000	166,500	156,000
2002	157,000	135,000	133,000	129,500
2003	204,000	178,000	170,000	158,000
2004	170,500	150,000	144,500	136,000
2005	196,000	159,000	154,000	147,000
2006	176,000	137,500	134,000	129,000
2007	198,500	175,000	167,500	161,000
2008	206,000	167,000	162,000	152,000
Average	177,000	162,000	158,000	148,000

Table 9. Combined scenario results for each year

Scenario	Existing Conditions (AC-FT)	Forecasted Conditions (AC-FT)	Extreme Conditions (AC-FT)	Armageddon (AC-FT)
1999	191,000	170,000	154,000	115,500
2000	206,500	182,000	165,000	124,000
2001	197,500	179,500	158,000	115,500
2002	157,000	150,000	139,000	107,000
2003	204,000	187,500	169,000	125,000
2004	170,500	157,500	143,000	107,000
2005	196,000	176,000	158,500	118,000
2006	176,000	164,500	149,000	111,500
2007	198,500	176,000	153,000	113,000
2008	206,000	164,000	149,000	112,000
Average	177,000	165,000	155,000	115,000

The following figures show how the reservoir operates for the given parameter. The reservoir's classification for all simulation is either fully functional or semifunctional depending on the percentage of occurrences and can be found in the Results and Discussion section (Figure 30 – 33).

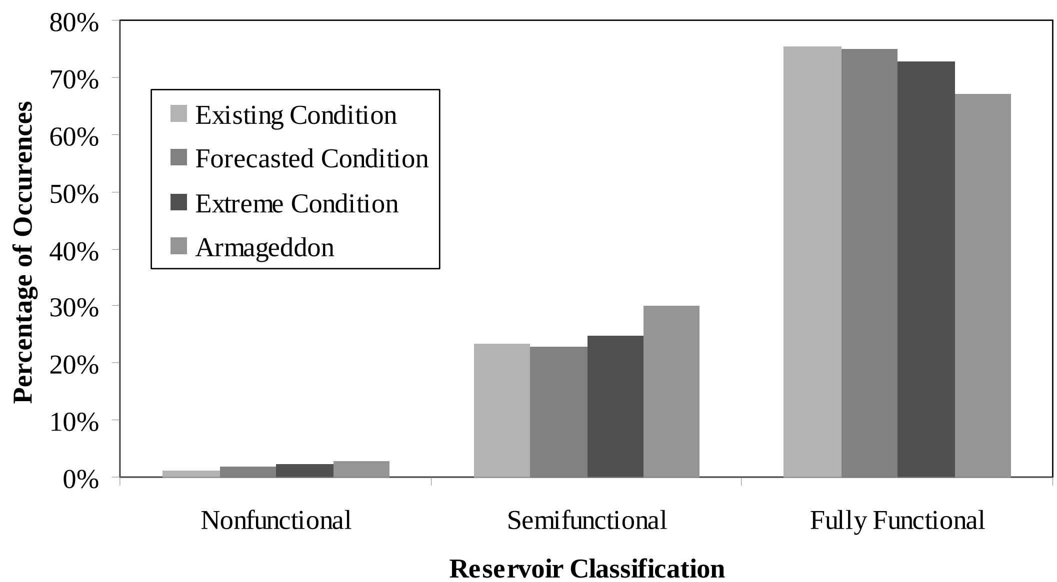

Figure 30. Temperature affect on the reservoir without energy development

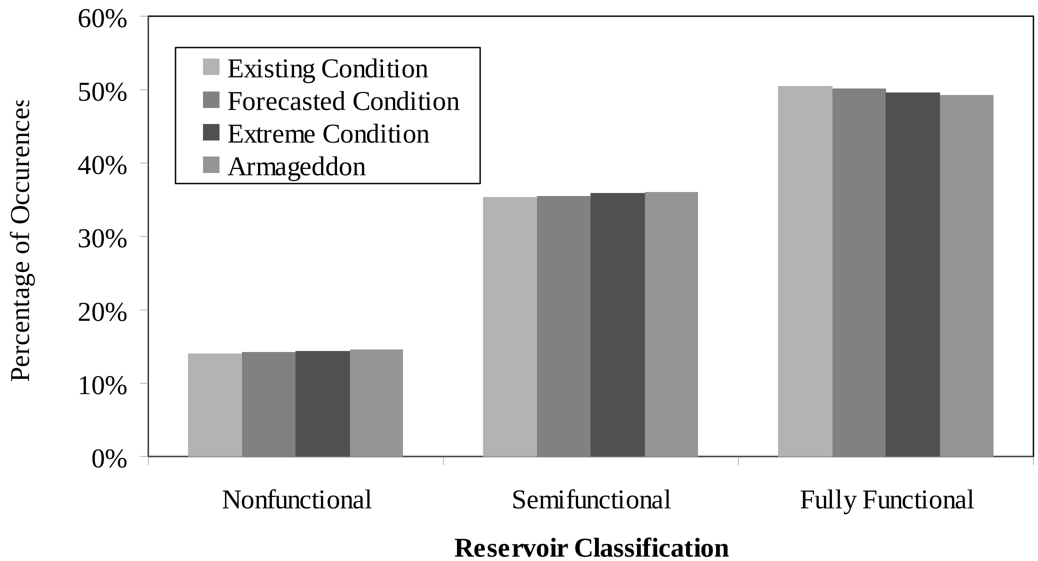

Figure 31. Temperature affect on the reservoir with energy development

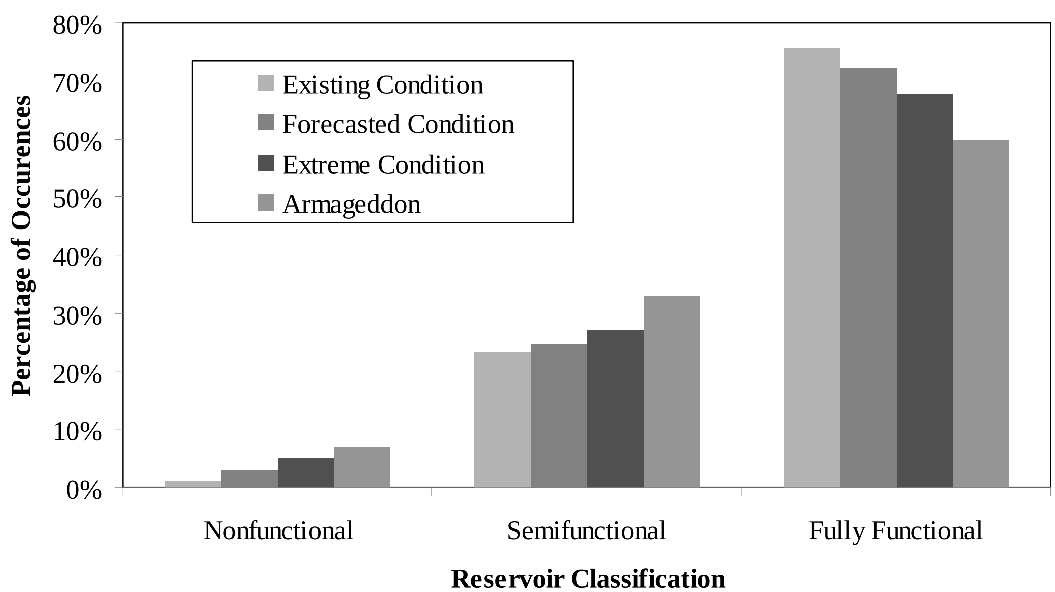

Figure 32. Precipitation affect on the reservoir without energy development

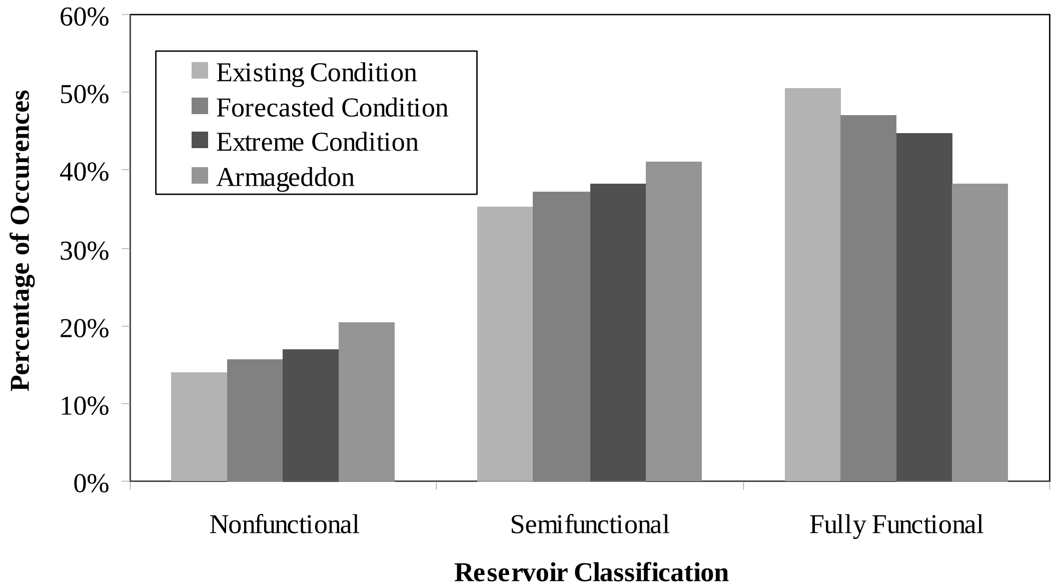

Figure 33. Precipitation affect on the reservoir with energy development

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